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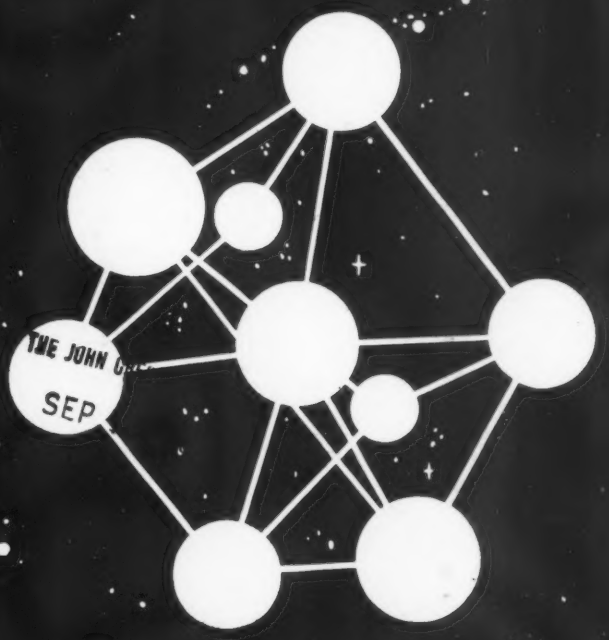

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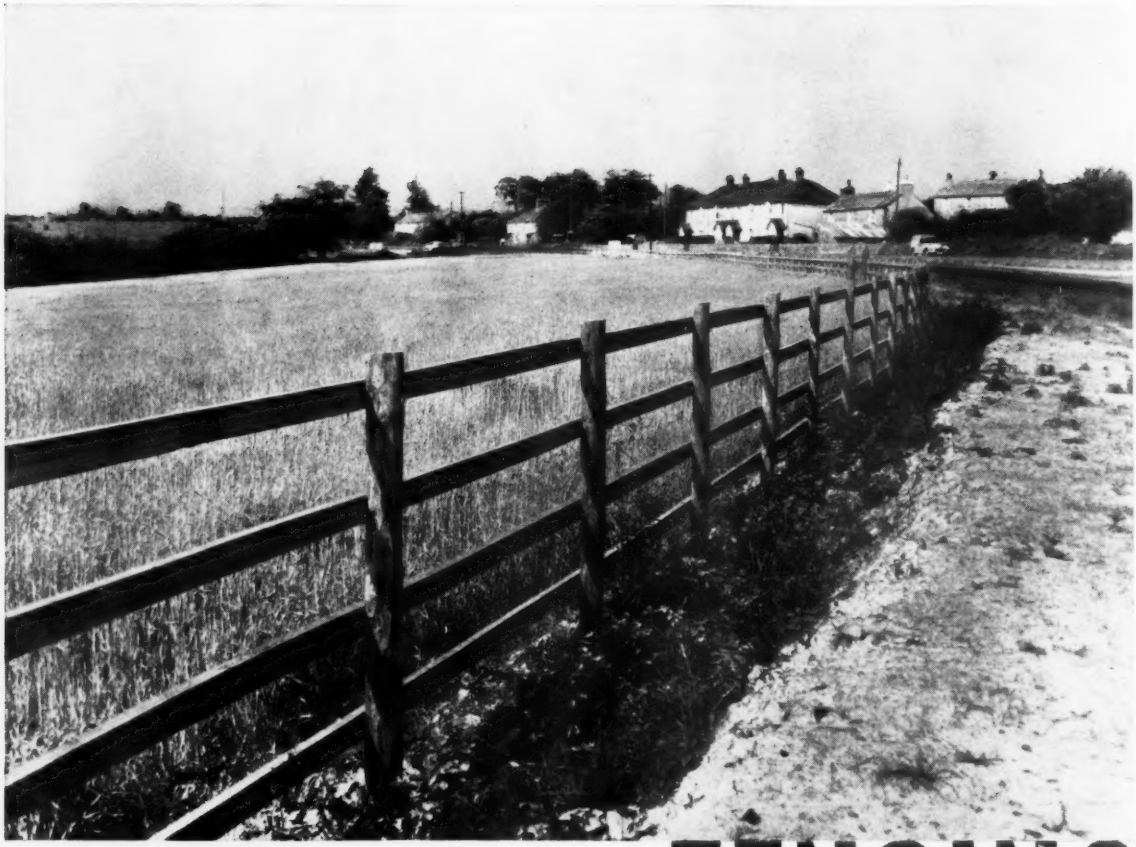

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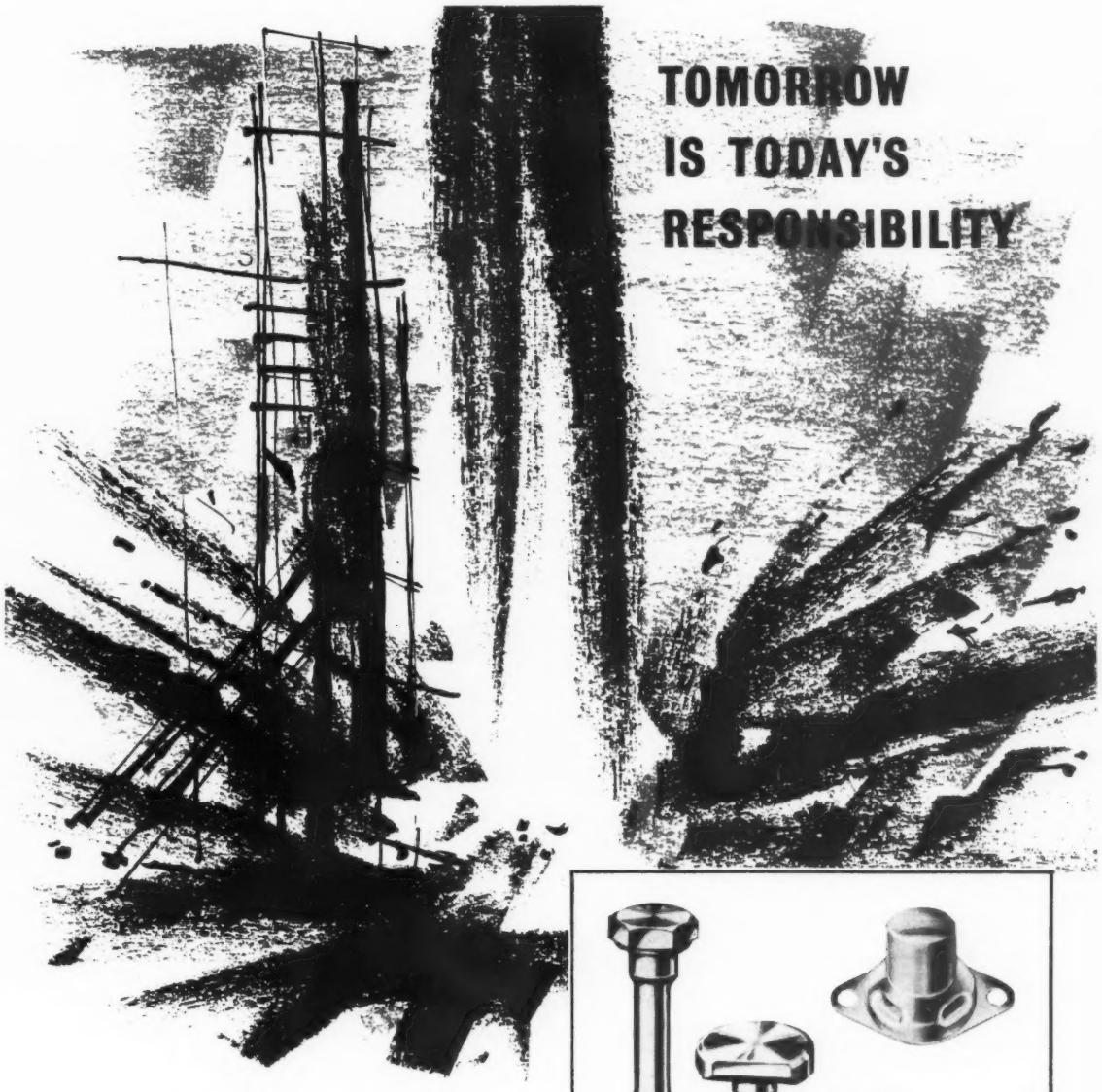


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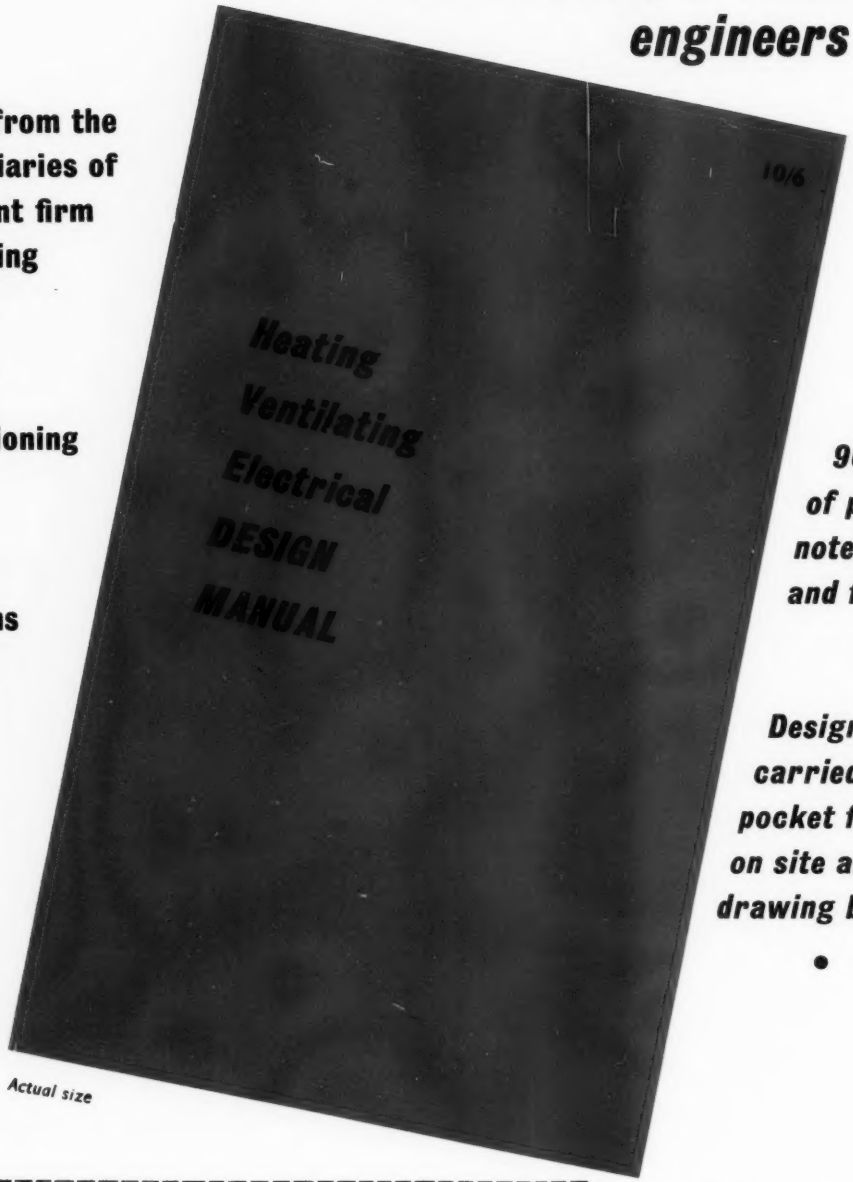


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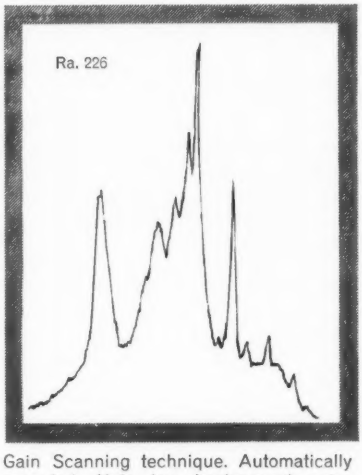


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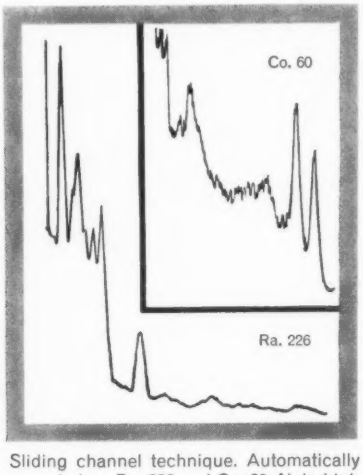


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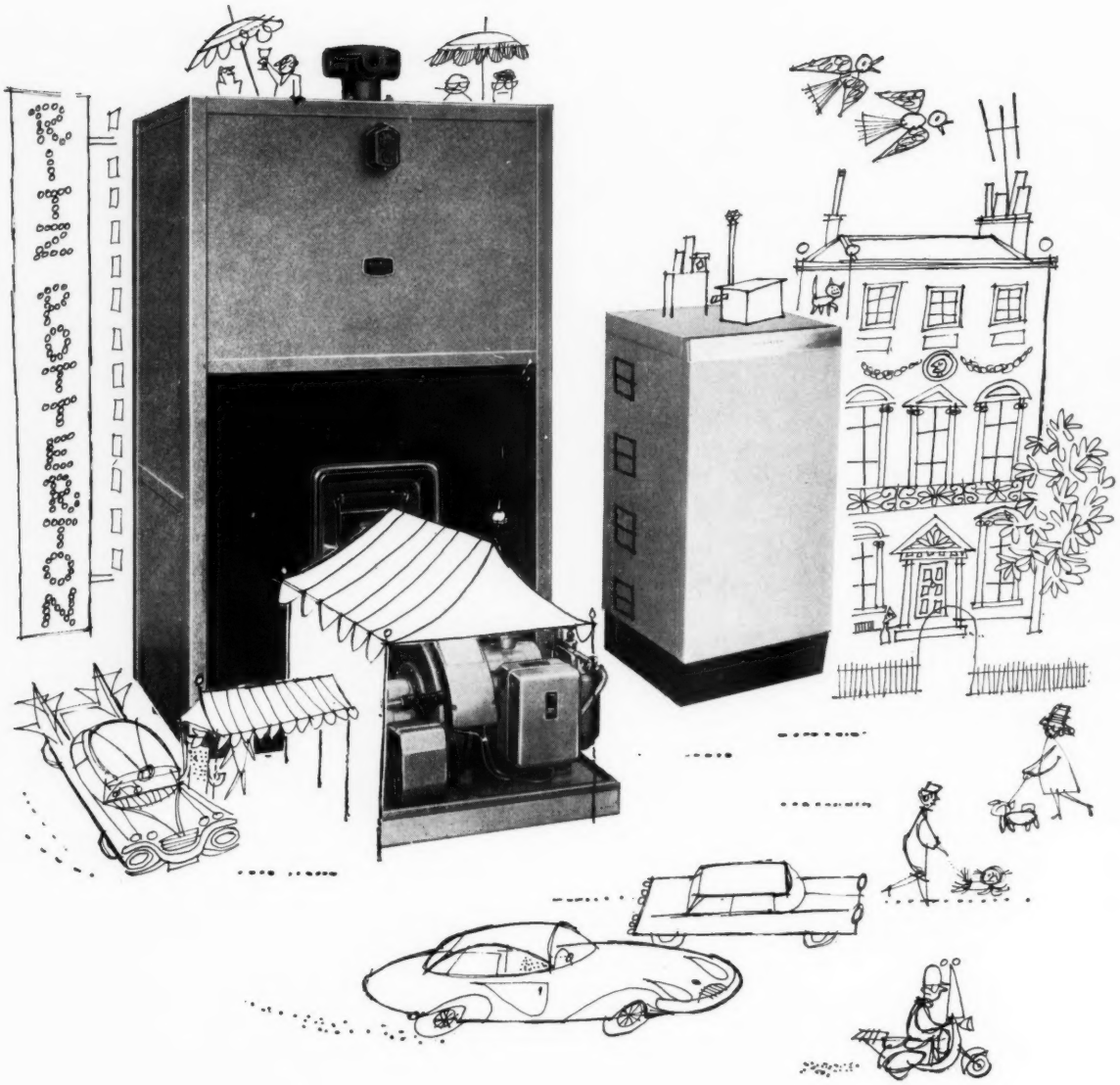

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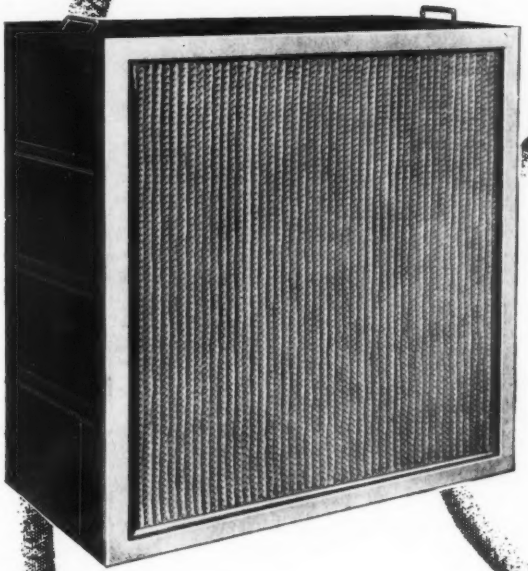

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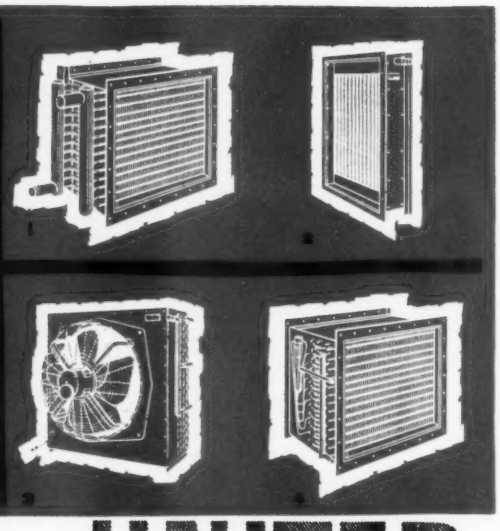

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## SEPTEMBER 1961

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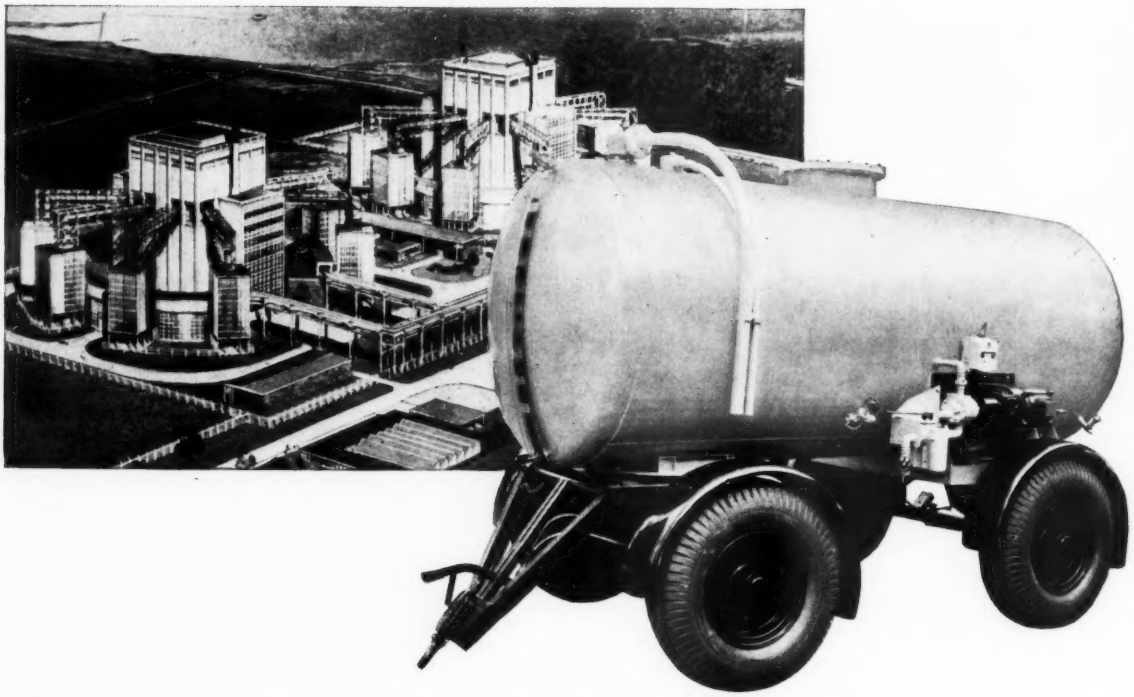

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# Classroom and Laboratory

**Arising out of a proposal by Dr. F. R. Paulsen, at a Council Meeting of the Institution of Nuclear Engineers, several hundred teachers of nuclear science were asked to report on simple apparatus and methods used or those which might be useful for practical demonstrations in instructional courses. The response was enthusiastic. From all parts of the world, from teachers in Universities, High Schools and Colleges, from research workers, manufacturers and public relations experts, have come many ideas. As a service to teachers, and also to other workers in nuclear fields, we are now publishing the many suggestions put forward. Each suggestion carries the identity of the person who put it forward, and also a reference number. The latter will facilitate enquiries sent in by readers requiring further information. Readers are invited to submit suggestions for inclusion in this feature**

## No. 80 Inverse Square Law

*Societe d'Applications Industrielles de la Physique, France.*

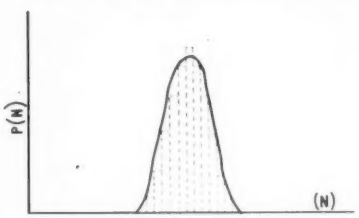
A suitable radioactive source (such as radiostrontium) is placed near the window of a GM counter and the count rate determined. The source is removed to a greater distance and counts repeated. This is repeated for several values of the distance $D$ between window and source. The count rates are plotted against $D^2$. It is seen that the count rate is inversely proportional to the square of the distance (the inverse square law), but that at the smaller values of distance there are deviations from this law. One reason for this is that at small distances there are inaccuracies arising from the high count rate, which may include many coincidences. No account has been taken here of the dead time of the counter. At very great distances, there is also another error which causes deviations. This is the radiation absorption by the air.

## No. 81 Gaussian Distribution

*Societe d'Applications Industrielles de la Physique, France.*

A radioactive source is placed near a GM assembly so that about 2,000 c.p.m. is recorded. Now 100 measurements are made of the count rate over periods of 10 sec. A histogram is constructed as in the previous experiment and compared with the theoretical Gaussian curve.

Let $nt$ be the mean value observed in an interval of time $t$. In the perfect Gaussian distribution the mean square error or standard deviation is $(nt)^{1/2}$. The value $n$ has a probability equal to 0·684 of lying within the interval given by the extremes $nt+(nt)^{1/2}$ and $nt-(nt)^{1/2}$. The value $N$ has also a 50 per cent. probability (*i.e.* 0·50) of lying between the values $nt+0{\cdot}675(nt)^{1/2}$ and $nt-0{\cdot}674(nt)^{1/2}$. The value $(2nt)^{1/2}$ is termed the precision. The probability that $N$ lies between the extremes $n+(2nt)^{1/2}$ and $n-(2nt)^{1/2}$ is 0·843. These values should be compared with those obtained from the histogram. For example, one may measure the frequency of readings deviating from the mean value by amounts greater



**Graph showing Gaussian distribution**

than $(2nt)^{1/2}$, $(nt)^{1/2}$ and $0{\cdot}674(nt)^{1/2}$ respectively.

These considerations make it clear that in radioactivity measurements it is necessary to give the statistical error by a careful selection of the definition of the error.

## No. 82 Gamma Ray atomic interaction cross-sections

*Department of Physics, Dartmouth College, U.S.A.*

In this experiment the object is to measure the absorption coefficients of 662 KeV gamma rays in iron and lead. The apparatus includes a 1C source of Cs137, iron and lead slabs, a GM counter and the associated circuitry. Analysis of the results yields cross section for Compton scattering from an electron and the photoelectric cross section in lead.

A slab interposed between the gamma source and the detector causes a reduced count rate, due to absorption of the gamma rays in the material. In Compton or inherent scattering, an electron in an atom scatters a gamma ray, the loss of energy of the latter being carried off by the recoiling electron. If the scattered gamma ray has an energy of $h\nu'$ and the incident gamma ray an energy $h\nu$, the scattering angle being $\theta$, then:

$$h\nu' = h\nu \Big/ \left(1+\frac{h\nu}{mC^2(1-\cos\theta)}\right)$$

$C$ being the velocity of light. The probability, or cross section, for this type of scattering, as calculated by Klein and Nishina, is proportional to $Z$, the number of electrons in the atom and decreases as $h\nu$ increases. This relationship holds strictly only for free electrons, but can be applied for bound electrons providing $h\nu$ is considerably greater than the atomic binding energies. In the photoelectric effect the gamma ray is absorbed by an atom, an electron being expelled with an energy equal to $h\nu$ minus the binding energy of the electron. At high energies the innermost or $K$ electrons are involved. The cross section for this process is proportional to $Z^5$ and decreases rapidly with increasing values of $h\nu$. In pair production a gamma ray passing near a nucleus vanishes, with production of an electron and a positon. This occurs only if $h\nu$ exceeds $2mC^2$ where $mC^2=511$ MeV. Excess energy is carried off as kinetic energy of the pair of particles. Annihilation of the positon, as it comes to rest, produces two gamma rays of energy 511 KeV each. Pair production cross section/atom is proportional to $Z^2$ and increases with $h\nu$. This pair production may also occur in the field of an electron, but at energies above $4mC^2$, but this is unimportant as an absorption process. There are other possible processes, although unimportant in gamma rays between 100 KeV and 1 MeV. These include the following: (*a*) Rayleigh or coherent scattering, in which the gamma ray scatters from the atom as a whole, with the same energy as the incident gamma ray, if we neglect the atom recoil

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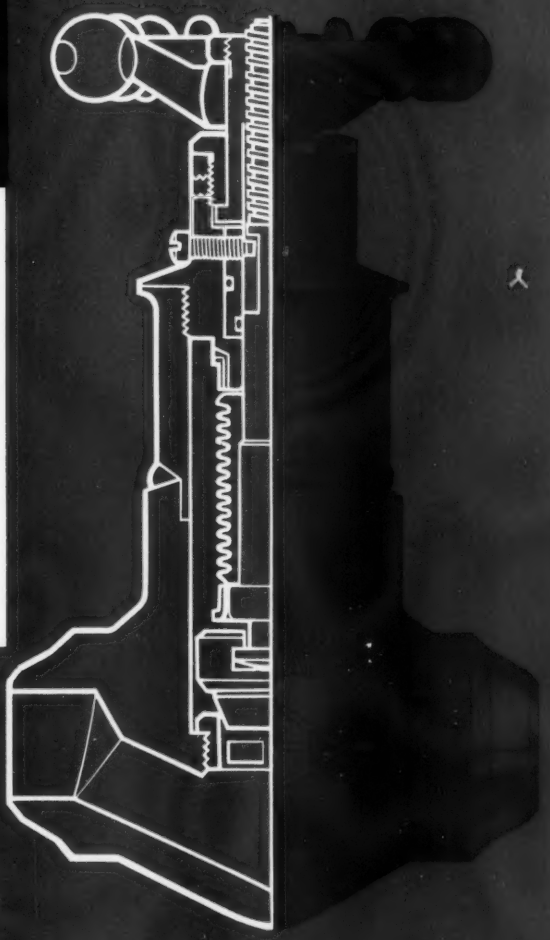

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energy. This results only with energies below about 100 KeV. The cross section for this process is proportional to $Z^2$ and is roughly inversely proportional to $(h\nu)^2$; (*b*) analogous to Rayleigh scattering is nuclear Thompson scattering, with a very small cross section and very difficult to measure; (*c*) Delbrach scattering, not so far observed, although predicted from theory. It should have a cross-section increasing with $h\nu$, but would be very small at 1 MeV.

In the experiment, lead bricks are set up carefully as shielding, the optimum design involving a compromise between counting rate and collimation. The source is to be located so that it may be easily removed and replaced periodically. Absorption coefficients are measured in lead and iron over as great a range of thicknesses as possible (at least 1 in. of lead and 2 in. of iron). Data should not be collected from zero thickness first, proceeding stepwise to greatest thicknesses. All points should be measured at least twice, some more often. The completed data should be a proof of the stability of the apparatus. It is wise to collect enough data at important points so that counting statistics become unimportant as a source of error. The background should also be measured several times during the period of the experiment. Time permitting, it is useful also to measure absorption coefficients at 1·25 MeV (Co60 sources emitting gamma rays in equal intensities at 1·17 and 1·33 MeV can be used.) The effect of changed geometry on the measured absorption coefficients might also be studied.

Great accuracy and good agreement with tabulated absorption coefficients are not to be expected. Precision measurements of absorption coefficients are difficult, especially with GM counters. As a result of this experiment it should be possible with GM counters. As a result of this experiment it should be possible to calculate the mass absorption coefficient $\mu$, in $cm^2/g$ for iron and lead; the Compton cross section/electron at 662 KeV; the photoelectric cross section of lead at 662 KeV; and results should be compared with tabulated values. In all cases an estimate of uncertainty should be tried.

## *No. 83 Point Counter for Radiation Detection*

### *E. Leybold's Nachfolger, Koln, Germany.*

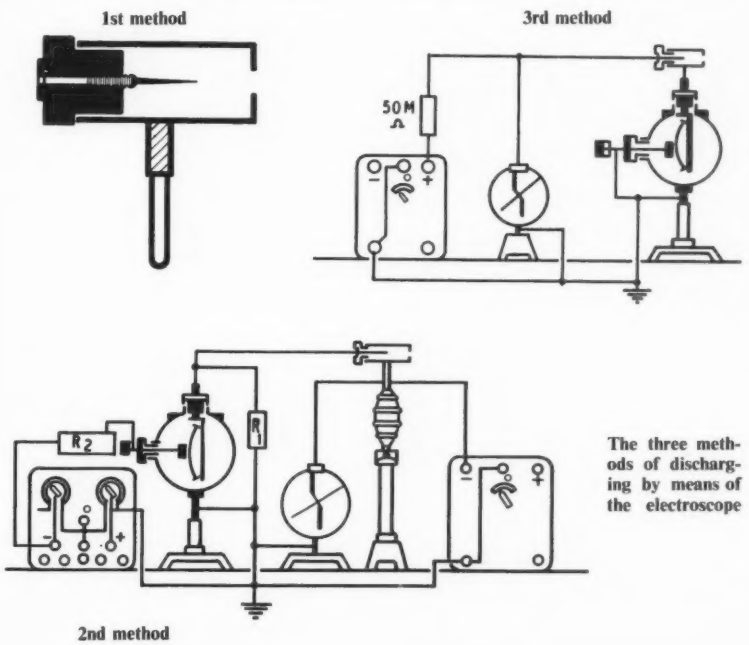
The point counter devised by H. Geiger in 1913, for the counting of alpha and beta particles, consists of a fine wire ending in a fine point and fixed along the axis of a metal cylinder and insulated from it. If a voltage is placed between the tube and the wire, there is an intense field at the point, and at a voltage just below breakdown an ionizing particle entering the cylinder causes a discharge by ionization. Discharges can be shown by means of the Wulf electroscope, which may be used in three different ways. In the first method, in which the voltage drop along a high resistance is measured, the circuit is so arranged that during discharge a pulse causes a voltage drop across the high resistance $R_1$ (about 1,000 megohm) and this is observed on the electroscope if the counter electrode is given a bias voltage sufficient to deflect the leaf to greatest sensitivity. This requires a second voltage source, connected to the counter electrode via the safety resistance $R_2$. The counter electrode is approached very closely to the leaf, causing a momentary deflection each time a discharge is initiated in the counter.

In the second method, in which a charge is collected, the leaf collects an increment charge at each impulse. The electroscope sensitivity increases with deflection, so that the deflections gradually become larger. Eventually the leaf jumps against the counter electrode, where it becomes charged and returns to zero, so that charging can recommence.

In the third method, the counter electrode is very close to the leaf, each discharge causing the leaf to strike, so that each impact represents an ionizing event in the counter. Weak sources should be used.

In all three methods the point of the counter must be kept very clean, well insulated and free from dust. The inner wall should be greased near the point, to retain dust particles which jump into the field. The cleaned counter should be screened with a thin aluminium foil, but this must be thin enough to be permeable to alpha particles. The counter works best when positively charged. When a gramophone needle is used as a point, it responds best at 3,000v. The release range, or range of voltage over which the particles cause discharges, is only less than 100v and at increased voltages self-maintained discharge occurs.

For these experiments an HT source is required for the point counter, and a power pack for the electrode bias. The counter electrode is drawn back far from the leaf, HT supplied and the counter electrode approaches a point where the leaf fails to strike.




**The three methods of discharging by means of the electroscope**

Suitable radio high resistances may be used, but matches, pencils, etc., can also be employed. A resistance which is too small will cause insignificant deflections, while if too high it will result in a leaf recharge which is too slow after deflection. In all these experiments the source is placed in front of the counter and the p.d. adjusted so that the deflections just commence in the electroscope when the source is in front of the counter window. When the source is removed, the leaf should remain at rest.

### *No. 84 Photoelectric Effect*

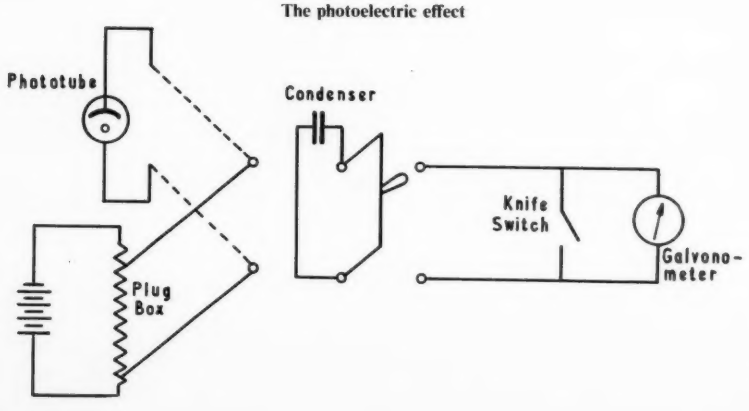
*Dartmouth College, U.S.A.*

The photoelectric effect, inexplicable on classical electromagnetic theory, was brilliantly explained by quantum theory. Einstein, in 1905, produced his theory, which may be summarized in the equation $\frac{1}{2}mv^2_{max} = hv - \phi$, where the first term is the maximum kinetic energy of electrons emitted by the photocathode, $h$ is Planck's constant and $v$ is the frequency of the light incident on the cathode. The last term, $\phi$, is the work necessary to remove the electron from the cathode. For the experimental demonstration of this effect, the apparatus required is a phototube (such as RCA 929) and a mercury source which produces a line spectrum. Specific lines of the spectrum are isolated by Wratten filters, suitable ones being 22, 49B and 74. The electron energy measurement is carried out with a condenser which is charged by the electrons emitted from the photocathode and then discharged through a ballistic galvanometer. The last is calibrated using known quantities of charge.

The maximum kinetic energy of the electrons emitted by a metal surface in the vacuum phototube can be measured by finding what voltage $V$, supplied between cathode and anode, will just prevent the fastest electrons from reaching the anode. This voltage depends on the wavelength of light with which the cathode is illuminated. Rather than measure the current as a function of retarding voltage, it is simpler to measure the charge collected on a fixed capacitor in parallel with the phototube. The capacitor will continue to charge until the voltage on the capacitor is sufficient to prevent the arrival of electrons of maximum kinetic energy at the anode. The voltage on the capacitor is measured by discharging it through a ballistic galvanometer. The galvanometer is previously calibrated as follows: The calibrated condenser is charged to a known voltage with a dry cell in parallel with a resistance plug box acting as voltage divider. The charged condenser is then discharged through the galvanometer and the deflection noted. A condenser is connected to the centre of a double-pole double-throw switch so that it can be connected either to the charging source, *i.e.* the battery or phototube, or connected to discharge through the galvanometer. The knife switch across the galvanometer is to assist in rapidly damping the system to zero after discharge.

The procedure in completing the measurement of $h$ requires a calibration of the galvanometer. Then a determination of the voltage needed to stop electrons of highest energy when the phototube is illuminated with light of known wavelength is carried out. This is done for three different wavelengths. By making a plot, one can obtain the values of $h/e$ and $\phi$. Before taking final data the following aspects of the problem must be investigated experimentally: charging and leakage characteristics of the capacitors; monochromaticity of the light transmitted by the filters; emission of electrons by anode as well as by cathode.

**The photoelectric effect**




### *No. 85 Radiations and the Distance Effect*

*John H. Woodburn.*

*Walter Johnson High School, Maryland, U.S.A.*

This experiment demonstrates, by a photographic technique, how the energy of radiations is lost as the distance from the source increases. A small plug of cotton wool is soaked in a few drops of a P32 solution, at a concentration of about 1 microcurie/ml. It is mounted on a toothpick placed on one end and inside a bootbox. In the darkroom, small pieces of X-ray film are placed 1, 2, 4 and 8 in. from the point source and so arranged that the radiations can have a clear path to each portion of film. The pieces of film are protected from beta particles by means of lead shields, in each of which three small holes are bored. The box is left for about 120 hours, well-shielded from light. The film is then developed, fixed, washed, dried and is then ready for mounting in a 2 × 2 in. slide binder so that it can be projected for study. The various sections of the film show clearly the effect of distance in attenuating the radiations.

### *No. 86 Selecting a detector for low level counting*

*Tracerlab, Inc., U.S.A.*

When dealing with radiations likely to give rise to low count rates there must be a compromise between the high cost of very sensitive instruments and the long counting times required to give accuracy at lower efficiencies. Assuming the error of measurement to be the only probable statistical error then percentage probable error in total net counts, $e =$

$$\frac{(\textit{total counts} + \textit{background counts})^{1/2}}{(\textit{net count})} = \frac{(\textit{net count} + 2\ \textit{background counts})^{1/2}}{(\textit{net count})}$$

the sample count and background count being made over the same time period. If the total net count =

(disintegration rate, $D$ of sample), $\times$(efficiency, $E$ of system) $\times$ ($t$ counting time) and background count = (background count rate, $B$) $\times$ (counting time, $t$), then we get:

$$e=\frac{(EDt+2Bt)^{1\times2}}{EDt}$$

from which it can be seen that

$$t=\frac{(ED+2B)}{e^2E^2D^2}$$

Accordingly, in order to reduce $t$ for an acceptable value of $e$, $B$ must be as small as possible and $ED$ as large as possible. Increased counting efficiency may be associated with increased background, especially if the detector size is increased and there may be insufficient material in the sample to take full advantage of the large detector.

Suppose we have two similar detectors differing in diameter by a factor of 2. The efficiency $E$, made up from factors involving the intrinsic efficiency, window and air absorption, geometry and self absorption, will be the same for both if the sample is loaded at the same weight/unit area. The larger counter, however, receives four times as much radiation if it deals with a sample four times as great and so its $ED$ value would be four times as great as that of the small counter. The background ratio of the two counters is roughly the ratio of their sensitive cathode surfaces and the effect of doubling the diameter and slightly increasing the height of the sensitive volume to maintain a uniform field is to give a factor of 2·6. Thus, for the two counters the times $t_1$ and $t_2$ required for net counts with an error $e$ will be in the ratio:

$$t_1/t_2=\left[\frac{ED+2B}{e^2E^2D^2}\right]\div\left[\frac{4ED+5{\cdot}2B}{e^216E^2D^2}\right]$$

$$=\frac{16(ED+2B)}{4ED+5{\cdot}2B}=6{\cdot}1$$

if the background rate is much greater than the net count rate. This assumes sufficient sample to make the small and the large samples infinitely thick with the same specific activity. Infinite thickness for $^{14}C$ is 20 mg/sq.cm, so that 100 mg would be required for a 1 in. sample and 400 mg for a 2 in. sample. If only 100 mg sample is available, 300 mg of carrier has to be added for the 2 in. diameter sample, without increase in net counts, so that :

$$t_1/t_2=\frac{ED+2B}{ED+5{\cdot}2B}$$

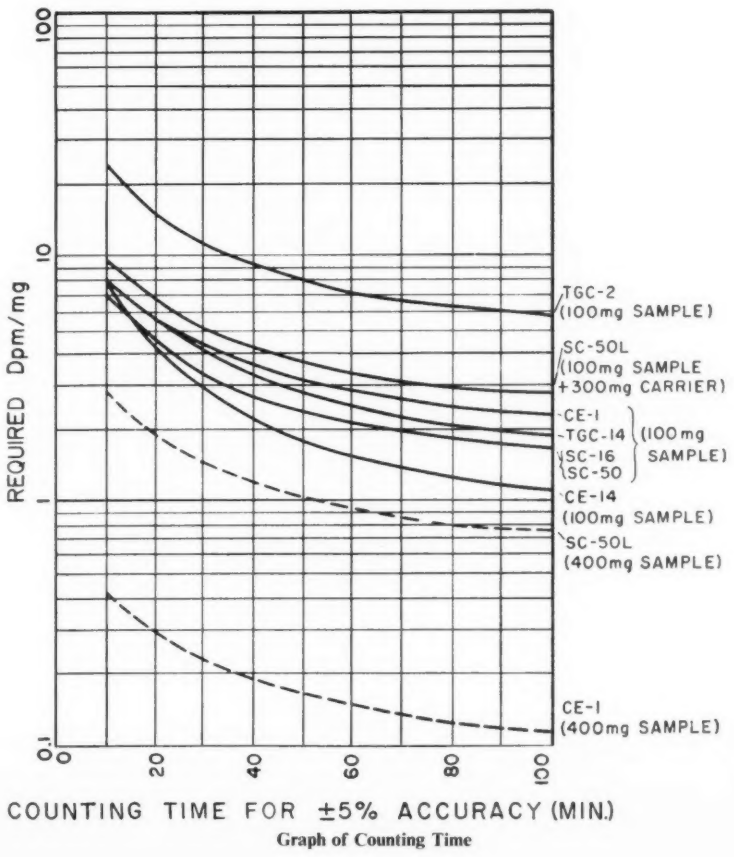
and measurements with the larger counter would take longer than those with the smaller counter.

Obviously, counters can be compared only when the sample size is taken into account. The choice of the counter must depend on efficiency, background and available sample size (see Table I).

These parameters can be used in the formula for $t$ and can give rise to a series of families of curves, one of which is shown here. This series shows specific activity in dpm/mg of a $^{14}C$ sample, plotted against the counting time required to give a statistical accuracy of $\pm5$ per cent. for a given amount of sample. The solid lines are for 100 mg of material, the maximum for a 1 in. sample. For the SC-50L automatic flow counter, having a 2 in. sample, dilution with 300 mg of inert material gives infinite thickness. The dotted lines are for larger samples and show the advantages of detectors which can cope with larger samples. △△△

**Table I.—Data for Tracerlab Counters**

| *Detector* | *Efficiency for infinitely thick $^{14}C$ sample, with self-absorption,* | *Background count rate, cpm* | *Sample required for infinitely thick $^{14}C$ sample mg* |
|---|---|---|---|
| TGC-2, Thin window GM | 3 | 25 in SC-59GS shield | 100 |
| TGC-14 C counter .. .. | 6 | 12 ,, SC-593 ,, | 100 |
| SC-16 windowless flow counter | 9 | 20 | 100 |
| SC-50A automatic windowless flow counter (1 in. D) .. | 9 | 20 | 100 |
| SC-50L automatic windowless flow counter (2 in. D) .. | 9 | 52 | 400 |
| CE-14 low background beta counter .. .. .. | 5 | 1 | 100 |
| CE-1 liquid scintillation counter .. .. .. .. | 50 | 60 | accepts about 1g |




**Graph of Counting Time**

# Nuclear Training and Research Equipment

*by Otto F. Joklik*

(*This article is continued from page 338 of our August issue*)

THE source is located in a lead cylinder so that a minimum gamma shielding thickness of 1·5 in. is presented at all times. Around the lead is a layer of paraffin wax 6·5 in. thick which, being composed largely of hydrogenous materials, effectively attenuates the neutrons.

Seven vertical experimental holes are located at intervals through the wax, as shown in Fig. 14, to enable the sampling of different flux densities to be performed.

The combination of gamma and neutron shielding coupled with distance attenuation reduces the overall dose rate on the outside surface of the apparatus to a safe level.

The following is the instrumentation supplied with the source of neutrons:

| | |
|---|---|
| Fast dekatron counter .. .. | Type D.4131 |
| Regulated power supply .. .. | Type D.4106 |
| Quenching pre-amplifier .. .. | Type D.4019/Q |
| Laboratory ratemeter .. .. | Type D.4101 |
| GM tube .. .. .. .. | Type MX 123 |

The following items are supplied as standard equipment:

| | |
|---|---|
| Tube mount and sample holder .. | Type D.4019/E |
| Foil locating mounts | |
| Handling tongs | |
| Foil tweezers | |

The active source capsule is lifted from its lead storage container using the handling tongs. The source rod, into which the source is to be placed, is held in an inclined vee block.

Having loaded the source into the rod, the rod is lifted with the handling tongs and lowered into position in the apparatus. The top cover plate is fitted and secured by means of the screws provided. The sliding portion of the cover plate of the equipment is closed and locked until the equipment is required for use. It is impossible to remove the source rod without first unlocking the sliding portion of the cover and removing the cover plate securing screws.

The apparatus affords a facility for training students in the basic techniques of nuclear radiation counting. Ample room for foil insertion is provided in the assembly and complete counting equipment is supplied.

Seven vertical holes with aluminium lining tubes are provided. The tubes, which are open at each end, pass right through the paraffin wax shielding. Thus if anything is dropped into a tube, it will fall straight through the assembly and hence does not have to be retrieved. The experimental holes are situated at various distances from the neutron source to provide different flux levels.

Seven foil holders, manufactured from Perspex, are supplied with the laboratory source of neutrons. They are calibrated in inches over a length of 1 ft, thus enabling the foils to be positioned accurately in the experimental holes.

A segment of the main body of the paraffin wax, in the vicinity of the experimental holes, is removable to

## Table II—Comparison of Research Reactor Types

| | *Approximate Average Thermal Flux (n/sq.cm—-es)* | *Approximate Cost Reactor** | *Typical Critical Mass* |
|---|---|---|---|
| **SOLUTION** | | | |
| Good flux at moderate power; very low critical mass; readily adaptable to variety of research; gross fission product isotopes (unseparated) are directly available in laboratory quantities | $2 \times 10^{11}$ at 10 kW to $1 \times 10^{12}$ at 40 kW | $125,000 to $225,000 | about 1 kg of U 235† |
| **POOL** | | | |
| Moderate critical mass requirements; large degree of flexibility in assembly and positioning of core; very adaptable for wide variety of research | $1 \times 10^{12}$ at 100 kW to $1 \times 10^{13}$ at 1,000 kW | $200,000 to $350,000 | 2·4 to 4 kg of U 235† |
| **TANK TYPE, LIGHT WATER** | | | |
| Highest neutron flux; large experimental facility; particularly valuable for materials testing | $2 \times 10^{14}$ at 30,000 kW | $6,000,000 | 4-6 kg of U 235† |
| **TANK TYPE, HEAVY WATER** | | | |
| Very high thermal flux; relatively low critical mass; large experimental capacity; particularly valuable for radioisotope production; enriched fuel required | $2 \times 10^{13}$ at 1,000 kW | $2,000,000 (with $D_2O_2$ inventory) | 1-3·8 kg of U 235† |
| **GRAPHITE** | | | |
| Largest experimental volume allowing in-pile irradiation of large objects and great research flexibility; enriched fuel not required | $2 \times 10^{12}$ at 28,000 kW | $10,000,000 | about 100 tons of natural uranium |

*Cost of reactor proper, not including fuel, housing and supporting facilities †In fuel of 20 per cent. or higher enrichment

**PRODUCTION OF RADIOACTIVE ISOTOPES**

| | *Approximate minimum neutron flux required (neutrons/sq.cm/sec)* |
|---|---|
| *Gamma Radiation Sources:* For example, naturally occurring Co59 bombarded by neutrons yields Co60 which upon disintegration gives off powerful gamma rays | |
| *Tracer Elements:* For example, a beta emitter, N14, forms C14, a 5,740-year-half-life beta emitter .. .. .. | $10^{10}$ to $10^{13}$ |
| For example, a beta-gamma emitter, Te130, forms I131, a 7-day-half-life, beta-gamma emitter | |
| **FUNDAMENTAL INVESTIGATION IN NUCLEAR SCIENCE** | |
| *Neutron Diffraction:* Neutron beams are used to study atomic structure; particularly useful to locate light and magnetic atoms which are not detected by X-rays .. .. .. .. .. .. .. .. .. .. .. | $10^{12}$ |
| *Cross-section Measurements:* Determining the interaction of neutrons with materials; the property of capturing or scattering neutrons is measured and expressed as the cross-section .. .. .. .. .. .. .. | $10^{8}$ to $10^{10}$ |
| **APPLIED RESEARCH IN POWER REACTOR DEVELOPMENT** | |
| *Shielding Studies:* Direct radiations from the reactor are used to study attenuation and capture in various combinations and geometries of material .. .. .. .. .. .. .. .. .. .. .. .. .. | $10^{10}$ to $10^{11}$ |
| *Radiation Damage to Materials:* Evaluation of the cumulative effect of radiations on the properties of materials used in construction .. .. .. .. .. .. .. .. .. .. .. .. .. | $10^{13}$ to $10^{14}$ |
| *Long Time Burn-up Evaluation:* Fuel materials are subjected to long-term irradiations to determine their stability .. | $10^{12}$ to $10^{14}$ |
| **MEDICAL THERAPY** | |
| *Cancer Treatment:* Neutrons bombard a B10 solution which has been absorbed selectively in cancerous tissue; the B10 emits short-range alpha particles which are very destructive to the diseased tissue .. .. .. .. | $10^{12}$ |
| **ANALYTICAL USES** | |
| *Chemical Tests:* Some materials are not made appreciably radioactive by irradiation, yet the included impurities may be readily activated. Impurities in irradiated samples may be determined in very minute amounts—up to one part per billion .. .. .. .. .. .. .. .. .. .. .. .. .. | $10^{12}$ |
| *Mechanical Testing:* For example, a material subjected to wear is irradiated prior to test; subsequently, as the radioactive material is worn away, samples are collected and monitored to determine rate of wear .. .. .. | $10^{11}$ to $10^{12}$ |
| **TRAINING IN REACTOR ENGINEERING** | |
| *Teaching:* Training in the fundamentals of reactor design, control and operation .. .. .. .. .. .. | to $10^{2}$ |
| *Research Problems:* Studying the fundamentals of reactors and performing original research experiments .. .. | $10^{5}$ to $10^{6}$ |

enable experiments on the reflecting and absorbing properties of various materials to be carried out.

The basic experiments which may be performed with the laboratory neutron source as supplied are (i) Geiger plateau determination; (ii) background determinations (iii) shelf ratios; (iv) statistical accuracy in counting; (v) half-life determinations; (vi) absorption of alpha, beta and gamma rays; (vii) health monitoring; (viii) reflecting and absorbing properties of materials; (ix) range of alpha, beta and gamma rays.

The Laboratory Source of Neutrons is a compact facility for carrying out a range of small scale nuclear experiments, being especially suited for those involving the activation of small foils. Some of these experiments are described below.

The shielding incorporated in the unit is designed to ensure that the radiation level outside the unit is everywhere less than 0·75 mr/hr. Thus health monitoring of persons using the apparatus is unnecessary.

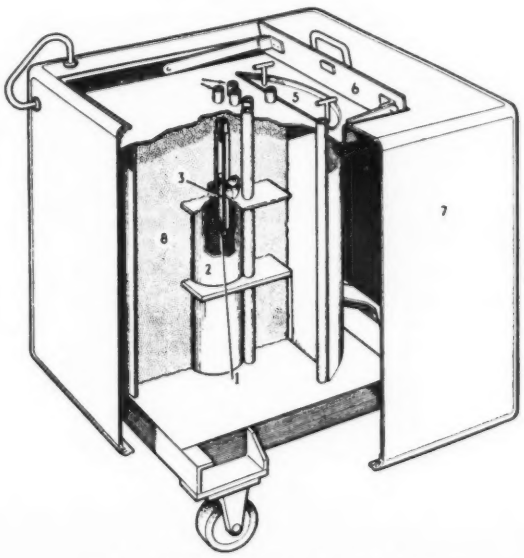



Fig. 14.—Vickers laboratory source of neutrons

## *Indium and silver decay curves*

(i) A small piece of indium foil was activated in one of the irradiation channels of the Laboratory Neutron Source. Using a GM tube and scaler unit, the decay curve shown in Fig. 16 was obtained. A time of two hours was required to complete the measurements.

The primary disintegration scheme for indium is:

$$In^{115} \xrightarrow{(n,\gamma)} In^{116} \xrightarrow[54{\cdot}2\ m]{\beta-} Sn^{116}$$

From Fig. 16 the observed half-life is 54 min, in excellent agreement with published data.

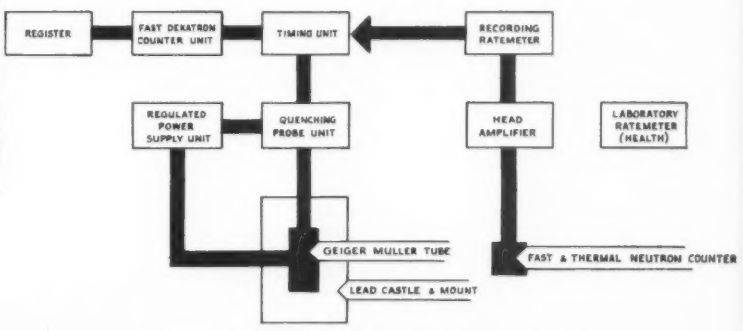



Fig. 15.—Block diagram of the basic instrumentation

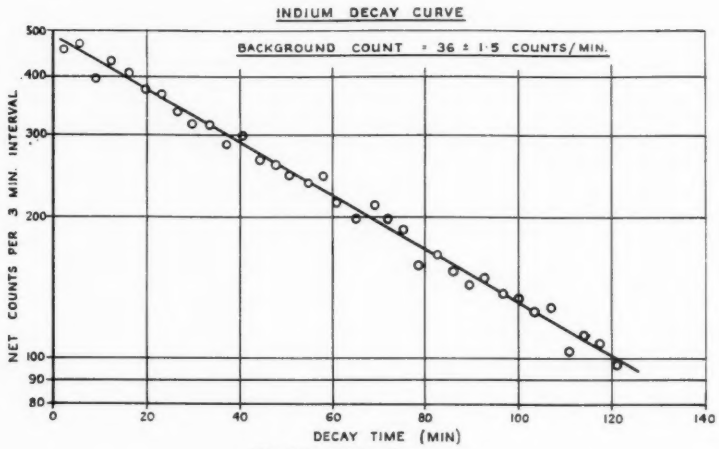



**Fig. 16.—Indium decay rate**

(ii) Using the same equipment as above with silver foil, a decay curve for silver was obtained (*see* Fig. 17).

As the intensity of activation was lower than before, a mean of the results from five foils was used. Two decay systems were observed; one with $T\frac{1}{2}=28$ sec, the other with $T\frac{1}{2}=1{\cdot}8$ min. The accepted decay scheme for silver which has been activated by thermal neutrons includes the following:

$$Ag^{107} \xrightarrow{(n,\gamma)} Ag^{108} \xrightarrow[2{\cdot}3\ m]{\beta-} Cd^{108}$$

$$Ag^{109} \xrightarrow{(n,\gamma)} Ag^{110} \xrightarrow[24{\cdot}2\ sec]{\beta-} Cd^{110}$$

As Ag107 and Ag109 are the main constituents of naturally occurring silver, and both have large activation cross-sections (45 and 113 barns respectively), one can expect to observe both decay schemes, which is in fact what has been noted in Fig. 17.

## *Table IV—Vickers Training Reactor*

| | |
|---|---|
| *Overall dimensions:* | 10 ft square including access staging less stairway |
| *Fuel:* | Natural Uranium |
| *Fuel Cladding:* | Aluminium |
| *Location Tubes:* | Aluminium–maximum configuration number 217 |
| *Core Horizontal dimensions:* | Hexagonal core 36·64 in. across corners, 31·92 in. across flats |
| *Core Height:* | 3 ft 6 in. |
| *Moderator:* | Light Water (double distilled) |
| *Reflector:* | Light Water–minimum thickness 7·2 in. (Effectively and infinite reflector) |
| *Containment Tank:* | Stainless steel |
| Depth | 5 ft 6 in. |
| Diameter | 4 ft 3 in. |
| Capacity | 340 Imp.gal |
| *Fuel Investment:* | 3·4 tonnes–natural uranium |
| *Lattice* | Consists of two grid plates which hold and position the location tubes |
| $k\infty$ | 0·94 |
| $k_{eff}$ | 0·82 |
| *Neutron Amplification:* | 9·0 |
| *Neutron Source:* | Polonium-beryllium. Provision is made for small multiple source insertions |
| *Total Weight:* | Completely assembled, including fuel and water–6 tons (approximately) |
| *Assembly Support:* | 6 in. thick concrete base |
| *Ceiling Height:* | A minimum ceiling height of 12 ft is recommended |

Experiments of the type described above may be developed to cover: (i) measurements of the activation cross-sections of certain elements; (ii) investigation of the " build-up " of radioactivity in an irradiated sample.

In addition, activation of foils in various positions in the channels allow certain properties of the unit to be examined, *e.g.*, (*a*) measurement of the thermal neutron attenuation in the paraffin wax shield and its relation to theory; (*b*) observation of neutron streaming in the irradiation channels.

With the removable segment taken out, further experimental work is possible, for example: (*a*) demonstration of the effectiveness of a sheet of boron or cadmium as a thermal neutron shield; (*b*) measurement of the variation of gamma attenuation with the thickness of an absorber, and comparison of different absorbers.

With suitable instruments a health survey of the neighbourhood of the unit may be made, verifying that the maximum dose rate is less than 0·1 m.p.l. (0·75 mr/hr). This facility is particularly useful as a training device for stimulating interest in nuclear physics. The performing of activation and radioactive decay experiments leads to a fuller understanding of the principles underlying these processes.

The experiments outlined here by no means form a comprehensive list of all that are possible. They indicate the type of work for which the apparatus is best suited, and with very little trouble, many additional experiments and variations may be devised.

### *Part III—Neutron and Gamma Irradiators*

A fully automatic mechanized gamma irradiation facility with multikilocurie Co60 gamma radiation sources is described. Certain constructive examples are given, in which the radiation source can either be immersed or the objects under exposure can be irradiated in any physical form, in bulk or continuously, beside the vertical rod-shaped radiation source in one or more parallel irradiation cylinders.

The irradiation can be switched off automatically either after a predetermined time (up to 120 hours) or after a certain dose (up to 50 millions of roentgens), and

the irradiation conditions can be varied at will from +450°C. to −160°C. at pressures up to 1,000 kg/sq.cm or in high vacuum.

### Industrial Scale

The large-scale industrial use of gamma radiation requires highly versatile research facilities with multi-kilocurie Co60 gamma sources, in which there should be as many possibilities of various irradiation conditions as possible, a " fail safe " operation and an easy handling of the samples to be irradiated.

The basic scientific research requires a versatile gamma irradiation facility, with a uniform distribution of the dose rate, the highest possible yield of the available gamma radiation and the possibility of obtaining a wide range of temperatures and pressures in the irradiation chambers.

This article refers to a fully mechanized and fully automatic gamma irradiation facility, fully self-contained and suitable for Co60 gamma radiation sources up to some 50,000 curies in high specific activity, providing a dose rate of about 50,000 to 50,000,000 of roentgens/hr, according to the curiage, specific activity and shape of the gamma source.

The irradiation may take place at various temperatures from +450°C. to −160°C. and at pressures up to 1,000 kg/sq.cm and in high vacuum as well. The time of irradiation, dose, etc., is controlled fully automatically and the singular irradiation cylinders, up to four, may be loaded independently from each other and observed by means of a TV camera and a TV screen with an automatic filming device for recording and reproduction of the irradiation experiments.

The objects to be irradiated may be exposed to gamma radiation either in bulk or continuously. In the latter case the continuous feed takes place by means of a special flange. The facility is fully self-contained and provided with an incorporated radiation shielding of high density lead which ensures an external surface dose rate inferior to 2 mr/hr.

The irradiation cylinders (object cylinders), up to four in all, are made of stainless steel and are provided with turntables of a diameter of 300 mm. They can be regulated to speeds from 0-60 rev/min and have a special gas exhaust and an explosion security valve of special design which has proved to be particularly interesting for the irradiation of hydrocarbons or other highly inflammable or explosive compounds.

The dimension of the irradiation cylinders is 400 mm in diameter and 600 mm in height. A special electric, hydraulic or pneumatic and mechanical interlock system ensures that the gamma radiation source can never be exposed during the loading or unloading of the irradiation cylinders. A special device enables the placing of the gamma source by means of a mobile mechanism in the centre of a reaction vessel or autoclave and the immersion of the gamma source into containers of various designs, thus utilizing the maximum of the radiation yield available from the gamma source.

A special protection of the gamma source against highly corrosive or viscous liquids is provided by a simple but effective device protecting the rod-shaped gamma source by a removable glass or plastic cylinder.

### Automatic control

The irradiation process in each of the irradiation cylinders may be controlled automatically either by means of a timer clock from 0-120 min and from 0-120 hr or by a preset number of roentgens, where the gamma source is shielded automatically either after the preset time is expired or after the preset number of roentgens has been irradiated. Precision radiation measurement instruments are built in in each irradiation cylinder and connected with external visual indicators and graphical chart recorders. Each irradiation cylinder is provided with an oscilloscope. The mechanical construction is a very simple one, all parts being easily accessible and interchangeable. The central block of the irradiation facility serves as the shipping container and for the

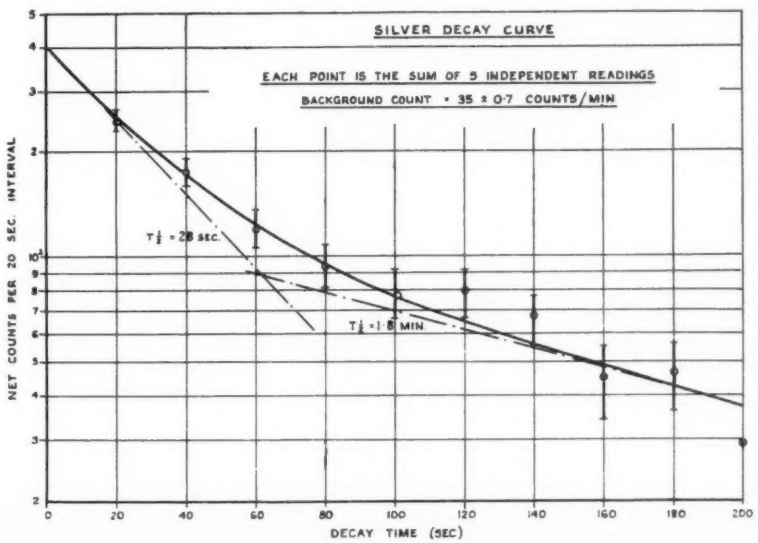



**Fig. 17.—Silver decay rate**

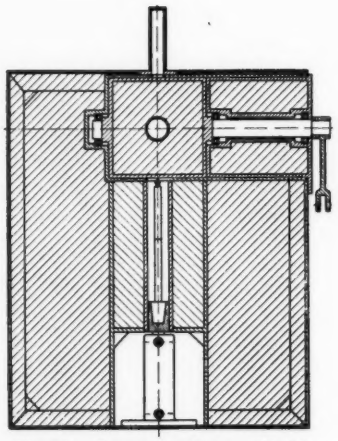


Fig. 18.—Gamma irradiator with rising radiation source. Gamma source in shielded position

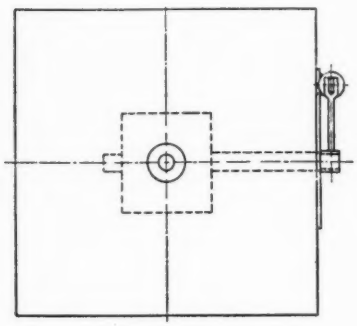


Fig. 19.—Upper surface of irradiator

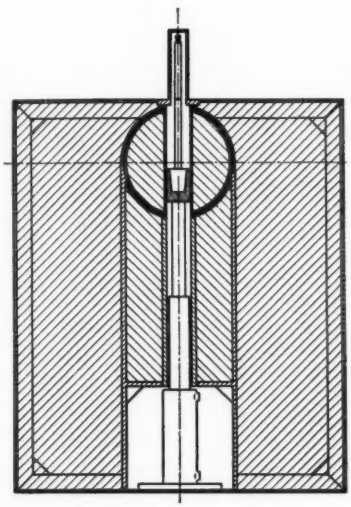


Fig. 20.—(*Right*) Cross-section of gamma irradiator

storage of the gamma source during modifications of the irradiation facility, when necessary.

### Basic types

The following detailed description refers to three different types of irradiation facilities which were designed with the intention of giving the research scientist a choice of various basic types easily adaptable to various research projects.

### Vertical gamma source

This unit consists of a lead-filled cube or cylinder about 1 cu.m in volume, in the centre of which the gamma source is located in a shielded position. After the application of various experimental arrangements of objects to be irradiated on the upper surface of the irradiator, the rod-shaped vertical gamma source is driven up hydraulically or pneumatically by means of a telescope cylinder.

The apparatus has, of course, to be placed in a room shielded with radiation proof concrete walls of approximately 1·25 to 1·80 m thickness. The lock of the access door to this shielded room has to be connected with the gamma radiation source exposure system in such a way as to ensure that the source may be exposed only after the door has been locked and *vice versa*. A mechanical telecommand consisting of a flexible hand-driven spindle makes the unit independent from the power system and eliminates any hazard of failure from network breakdown. etc. The scheme of this apparatus is shown in Fig. 18, 19 and 20. Fig. 18 shows a vertical section with the gamma source in shielded position, Fig. 19 the upper surface and Fig. 20 shows the source in exposed position.

The shielding of the gamma source against the upper surface of the apparatus is ensured by a horizontal lead-filled cylinder of about 300 mm diameter with a drilling in the middle, somewhat larger than the maximal diameter of the vertical gamma source. The cylinder itself is moved by means of a hydraulic or pneumatic drive connected to the driving mechanism of the gamma source and to the access door of the shielded room by an interlock system.

A simple rotation of the lock cylinder places the drilling vertically above the gamma source and allows the latter to be driven upwards to its exposed position to protrude above the upper surface of the apparatus.

Its overall cost, including radiation measure and control instruments, interlocks, automatic and manual commands, etc., but without basements, masonry and the radiation source, amounts to approximately $19,000.

The gamma irradiator as described above is applicable to gamma sources up to 50,000 curies Co60 and its specific advantages are simplicity, ruggedness and the possibility of driving the exposed source of radiation into

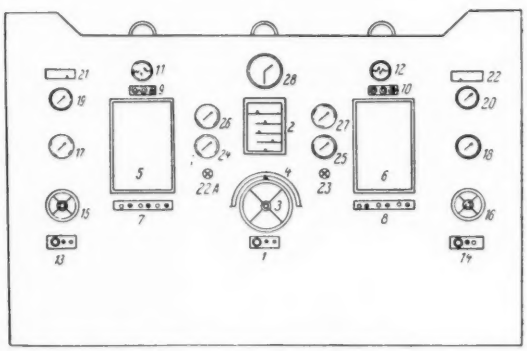


Fig. 21
(*Far left*) Irradiator with opened loading door and shielded gamma source

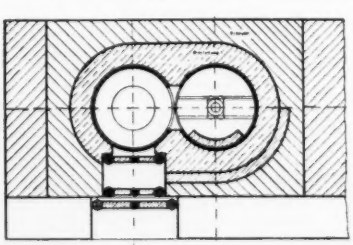


Fig. 22
(*Left*) Irradiator with closed loading door and exposed source

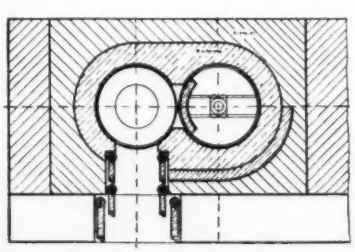


Fig. 23
(*Above*) This irradiator weighs about 12 tons and measures 2,900 mm × 1,800 mm × 1,200 mm

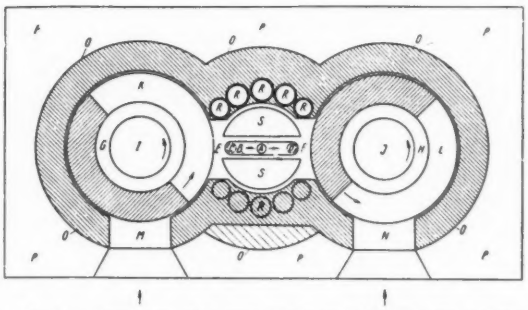


Fig. 24.—Irradiator with one source cylinder and two object cylinders

any container, pressure vessel, etc., thus utilizing the maximum of the available gamma radiation.

### Self-contained irradiator

This type consists of a completely lead-shielded irradiator in the form of a case, with the rod-shaped vertical gamma source located in a stainless steel cylinder (source cylinder). The objects to be irradiated are introduced into a parallel cylinder (irradiation or object cylinder) through a hydraulically or pneumatically driven lead-filled door. The second cylinder is also made of stainless steel and is equipped with a turntable which can be adjusted to various speeds. Both cylinders have thick lead-filled walls and a rectangular opening (window) of equal dimensions.

For irradiation, the openings of both cylinders are facing each other, thus allowing gamma radiation to pass from the source cylinder to the object on the turntable of the second (object or irradiation) cylinder. The loading door is simultaneously and automatically shielded by the lead-filled wall of the object cylinder.

By turning a central dented wheel placed on strong ball bearings within the two cylinders, the openings are moved in opposite direction, thus interrupting the irradiation process while automatically shielding the gamma source and placing the opening of the object cylinder facing the loading door. After opening the latter the irradiated objects on the turntable are accessible from the outside.

The central drive of both cylinders is commanded hydraulically or pneumatically and an interlock system ensures that the door to the object cylinder can never be opened with the radiation source in the exposed position.

Radiation measurement instruments, TV installation and special flanges for the application of a continuous feed system, additional devices, etc., complete this irradiator.

The special advantage of this unit is to be seen in the possibility of erecting it in any laboratory or other room with suitable basement without the need of any further radiation shielding, the outside surface dose rate of the apparatus being inferior to 2 mr/hr. The only disadvantage is the rather limited exploitation of the available radiation, which may be increased, however, by placing from one to three additional object cylinders around the central vertical gamma source and by allowing a special shielded container to be placed around the radiation source from above, thus enabling a direct immersion of the source into such a container, ensuring the maximum yield of the available radiation.

Fig. 21 shows the irradiator with opened loading door and shielded gamma source, Fig. 22 shows the irradiator with closed loading door and exposed source. In this scheme the irradiator consists of one source cylinder and one object cylinder.

An apparatus as shown in Fig. 23 weighs about 12 tons, its dimensions are 2,900 mm × 1,800 mm × 1,200 mm and its overall cost including control instruments, TV installation, shielding, etc., but without the radiation source, amounts to $29,000.

Fig. 24 shows a similar apparatus with one source cylinder and two object cylinders. A similar arrangement with three object cylinders is shown in Fig. 25, while Fig. 26 shows an arrangement of four object cylinders around a central vertical gamma source. The weight of the multicylindrical gamma irradiator is of course higher than the previously mentioned figure for a monocylindric unit and can total as much as 25 tons, depending on the quantity of lead shielding.

The gamma irradiator as described above is applicable to gamma sources up to 30,000 curies Co60. The maximum of four object cylinders ensures four independent working places with each of the object cylinders freely and independently accessible, thus allowing simultaneous work on four different research projects.

### Combined irradiator

This type is a combination of the two previously described models: the unit has a central shielded container and the mobile gamma source can be driven up from its shielded position into an irradiation room shielded by lead-filled steel walls calculated to guarantee an external

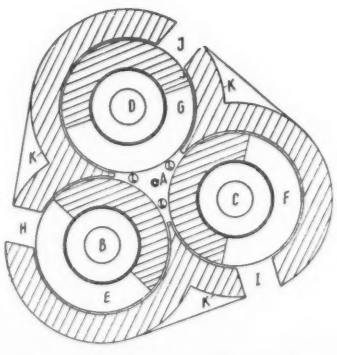


Fig. 25.—Arrangement with three object cylinders

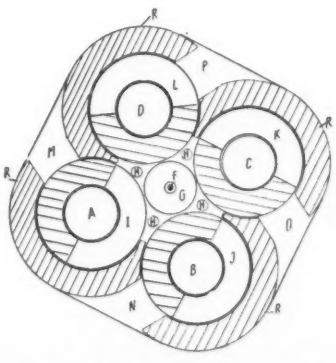


Fig. 26.—Four object cylinders arranged around a central gamma irradiator

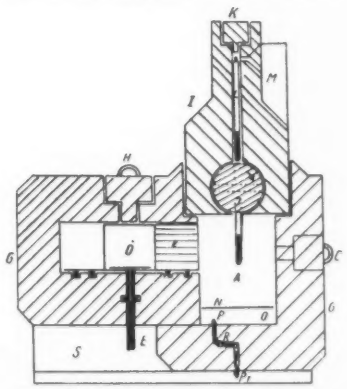


Fig. 27.—Upper source container for combined gamma irradiator

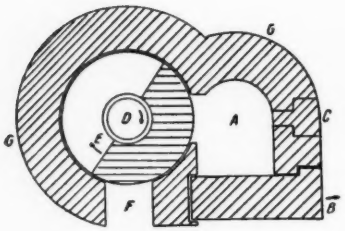



**Fig. 28.—Additional irradiation cylinder for combined irradiator**

surface dose rate inferior to 2 mr/hr. The reversed arrangement is possible, too, with the gamma source driven down into the irradiation room.

These arrangements are shown with the upper source container in Fig. 27 and with the lower source container in Fig. 29. Near the main irradiation room, parallel to the exposed vertical gamma source, there is an additional irradiation cylinder shielded by means of a rotating lead-filled cylinder segment alternatively against the exposed source to allow the introduction of the objects to be irradiated or against the loading opening during the irradiation. Fig. 28 is a cross-section of both arrangements and both irradiation rooms with their shielding systems.

The lead-filled front door of the main irradiation room is actuated by a hydraulic or pneumatic power system and an interlock system ensures that it may never be opened with an exposed radiation source in an unshielded position and *vice versa*. An irradiator of this type weighs about 25 to 30 tons and is applicable to gamma sources up to some 50,000 curies Co60.

An irradiator of the described design has the dimensions of 2,000 mm × 2,600 mm × 1,600 mm and its overall cost, including shielding, automatic control, servomechanisms, radiation measure and control instruments and TV installation but without gamma source, amounts to about $39,000.

Two additional irradiation cylinders may be arranged around the central irradiation room, thus ensuring four independently accessible irradiation places. The total weight of the apparatus then increases to 30 to 35 tons. Owing to the considerable weight of the unit its assembly can be done on rails outside the ultimate place of installation, the weight of each part not exceeding 6 tons. In this way, assembly is considerably simplified. The particular advantage of this type is its universal applicability.

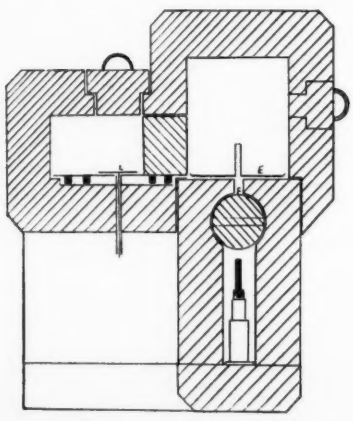


**Fig. 29**

Additional devices allowing a continuous feed of the products to be irradiated in any physical form and providing a heating or cooling of the object cylinders to ensure working temperatures from +450°C. to −160°C. are available for all previously described types of gamma irradiators. Additional high pressure vessels, autoclaves, etc., may be built into the object cylinders, thus ensuring irradiations at pressures up to 1,000 kg/sq.cm as well as in high vacuum. Further devices, such as magnetic or other stirrers, additional measurement instruments, TV cameras, connections to external pilot plant of any design for studies of continuous processes, etc., enable a practically unlimited variety of research conditions in rather complex arrangements and even in the semi-technical continuous experimental stage.

## *Part IV—Conclusion and Outlook*

The 149 Western European universities at present take in more than 900,000 students, 200,000 of them scientific. It should be emphasized that almost 15 per cent. of these students come from other continents: Asia, Africa, South America. Of these 200,000 science students in Western Europe, about 12,000 are involved in the field of nuclear science.

At the moment a dozen or so courses of at least three months are organized in Europe for the training of scientists in atomic energy subjects. Some 100 professors are teaching the nuclear sciences across the various branches of mathematics, physics, chemistry, engineering and biology.

For these students the universities need reactors, subcritical assemblies, reactor simulators, particle accelerators and various apparatus and instruments for study, training and research purposes.

Once more the European Science Faculties and Technical Institutes are playing their part in the general competition of scientific discovery and will continue to do so. Thus nuclear studies, which 10 years ago had little place in the European universities, are now becoming of ever-increasing importance and are attracting students from other continents.

**TABLE V**

**Reactor Training and Research Equipment at European Universities**

**(August, 1960)**

| Country | Reactors Active | Subcritical Assembly | Reactor Simulators |
|---|---|---|---|
| Austria .. .. | 1 | | |
| Belgium .. .. | | | |
| Denmark .. .. | | | |
| France .. .. | 1 | 2 | 1 |
| Great Britain .. | 3 | 6 | 2 |
| Germany .. .. | 5 | 1 | 1 |
| Greece .. .. | | | |
| Ireland .. .. | | | |
| Italy .. .. | 3 | | |
| Netherlands .. | 1 | | |
| Norway .. .. | 1 | | 1 |
| Portugal .. .. | | | |
| Sweden .. .. | 1 | | |
| Switzerland .. | 3 | | 1 |
| Turkey .. .. | | | |
| Yugoslavia .. | | | |

From a study of the above data a number of the following facts emerge:

(1) It is mainly in countries which until then had no big atomic centres that the universities have made the biggest effort to possess reactors, as *p.e.*, in Germany or Italy.

(2) In general the reactors were built by English or American firms—a university having neither the material means nor the competence to produce a reactor alone.

(3) Funds were generally obtained from the State, either through the National Atomic Energy Commission or the National Ministry of Education.

(4) The safety problems have been solved in various ways according to the individual situation.

(5) If a study is made of the various types of reactor used, it will be noted that, classing as research reactors all those with at least 400 kW power, the 19 university reactors in Europe divide up as follows:

7 research reactors (4 swimming-pool type, 3 $U/D_2O$ reactors)

12 educational reactors (6 Argonauts, 4 homogeneous reactors, 2 swimming-pool reactors)

(6) Among the reactors under construction or at an advanced planning stage, the Argonaut type appears to be quite popular.

(7) The European universities are beginning to be well equipped in the way of reactors. This policy has the following advantages: university professors have and will have at their disposal, on their own premises, only reactors of relatively low power, mainly for educational purposes. For original research work the universities and their students have to use the reactors in the atomic centres.

The author wishes to express his thanks to the staff of Vickers-Armstrongs (South Marston), Ltd., for their most helpful assistance and support.

## APPENDIX I

### Basic Research Requirements for Training Reactors

Tracing of flux charts.
Study of fine structures—determination of $\varepsilon$, $\gamma_i$, $\rho$, $\delta$.
Lattice studies (if the central block can be removed).
Multiplication coefficient.
Sub-critical approach
—by successive loadings and
—by adjustment of *p.e.* the water level.
Temperature coefficient measurement.
Cross-section measurements by time of flight and transmission methods and by oscillation method.
Operating experience: criticality, calibration of control rods and power chambers, and thermodynamic (balance).
Crystal spectrometry of neutrons.
Irradiation of short-lived radioelements.
Safety measurements: $\delta$ and $\gamma_i$.
Poisoning measurement of migration areas.
$\delta$ and $\gamma_i$ dosimetry in the channels, etc.
A training reactor should have a large number of loops and channels for research purposes:
Pneumatic loop for the production of short-lived radioisotopes.
Neutron diffractometer.
Channel for irradiation at liquid nitrogen temperature (80° K.).
Cell for irradiation under a magnetic field (2,500 oersteds) between 80° and 500° C.
Cell for action of hydrogen under irradiation at 800° C., etc.

## DESIGN DATA

## APPENDIX II—OUTLINE OF A TRAINING PROGRAMME AND COURSES ON NUCLEAR ENERGY FOR STUDENTS AND GRADUATES

### Institute of Electronics, Electronic Studies Centre, Rome, Division of Atomic Physics and Nuclear Technology

Basic subjects taught:

1. Nuclear physics applied to nuclear power
2. Reactor theory and reactor engineering
3. Heat technology and thermodynamics applied to nuclear reactors
4. Electronic instruments and engineering for nuclear power
5. Preparation and processing of nuclear source materials and fissionable materials
6. Metallurgy of metals used in connection with nuclear power
7. Prospection and extraction of uranium and thorium ores
8. Production and use of radioactive isotopes
9. Biological and chemical effects of radiation
10. Radiobiology
11. Industrial application of radiation
12. Radiochemistry
13. Protection
14. Meteorology
15. Applied gamma radiation technology
16. Economics of nuclear power and applied radiation

A **First cycle** (Basic Introduction)

1. **Nuclear physics:**
   - 1.1 General nuclear physics
   - 1.2 Methods of measurement
   - 1.3 Electronic instruments
   - 1.4 Particle accelerators
   - 1.5 Elementary particles
2. **Reactor building materials**
3. **Separation of isotopes, particularly of hydrogen and uranium**
4. **Elements of radiochemistry**
5. **Effects of nuclear radiations on matter**

B **Second cycle** (Advanced Introduction)

1. **General theory of nuclear reactors:**
   - 1.1 Types of reactors
   - 1.2 Thermodynamics of nuclear reactors
   - 1.3 Power reactors
   - 1.4 Building elements for nuclear reactors
   - 1.5 Fuel elements
   - 1.6 Regulation and control of nuclear reactors, reactor simulators
   - 1.7 Reprocessing of nuclear fuels
   - 1.8 Waste
2. **Production and utilization of radioisotopes**
3. **Biological effects of ionizing radiations, methods of protection**
4. **Economic aspects of nuclear energy**

C **Third cycle** (Radiation Technology)

1. **INTRODUCTION**
   - 1.1 Outline of Programme
   - 1.2 Historical Development
2. **THE FUNDAMENTALS OF RADIOACTIVITY**
   - 2.1 **The Atom**
   - 2.11 The Nucleus—Neutrons, Protons, etc.
   - 2.12 The Outer Atom
   - 2.2 **Types of Radiation**
   - 2.21 Alpha
   - 2.22 Beta
   - 2.23 Gamma
   - 2.231 Electromagnetic Radiation—The Spectrum
   - 2.232 The Photon
   - 2.233 X-Rays and Gamma Rays
   - 2.234 The Spectra of Ir192, Co60, Cs137, Tm170
   - 2.24 Neutron and Other
   - 2.25 Radioactive Decay
   - 2.251 Exponential Nature
   - 2.252 Half-Life-Computations

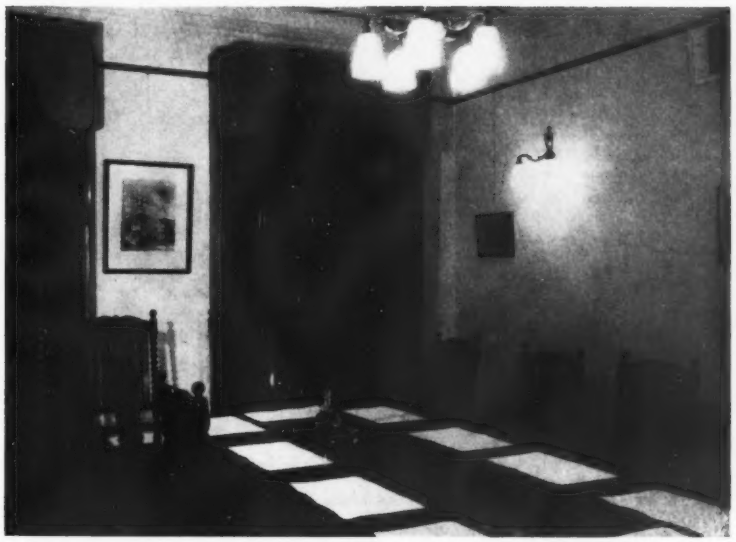
3. **THE INTERACTION OF RADIATION WITH MATTER**
   - 3.1 **Interaction of Alphas**
   - 3.2 **Interaction of Betas**
   - 3.21 Radioactive Interaction
   - 3.22 Ionization
   - 3.3 **Interaction of Gammas**
   - 3.31 Compton-Effect
   - 3 32 Pnotoelectric Effect
   - 3.33 Pair Production
   - 3.34 Secondary Radiation
   - 3.35 Scatter of Gamma Radiation
   - 3.36 Cross-sections—Computations
4. **DETECTION OF RADIATION**
   - 4.1 **Particle Counters**
   - 4.2 **Ion Chambers**
   - 4.3 **Electrometers**
   - 4.4 **Detection With Film**
5. **PRINCIPLES OF SHIELDING**
   - 5.1 **The Inverse Square Law**
   - 5.2 **Absorption**—Principles, Use of Coefficients
   - 5.3 **Shielding Data** for Co60, Ir192 and Cs137
   - 5.4 **Simple Shielding Computation**
6. **THE HEALTH PHYSICS OF RADIATION**
   - 6.1 **Units**
   - 6.11 The Roentgen
   - 6.12 The Roentgen-equivalents
   - 6.2 **Biological Effects of Radiation**
   - 6.21 The Biological Target and Biological Response
   - 6.22 Doses Required for Various Biological Effects
   - 6.23 Chemical and Physical Protection
   - 6.24 Radiation Injury
   - 6.3 **Dose and Dose Rate Standards**
   - 6.4 **Detection and Measurement Instruments—Principles and Applications**
   - 6.41 Survey Instruments
   - 6.411 Geiger Müller
   - 6.412 Ion Chamber
   - 6.42 Dosimeters
   - 6.43 Film Badges
7. **RADIOISOTOPES IN SCIENTIFIC RESEARCH**
   - 7.1 **General**
   - 7.2 **Design of Research Gamma Irradiators**
8. **INDUSTRIAL USE OF RADIOISOTOPES**
   - 8.1 **Density and flow measurements**
   - 8.2 **Gamma Radiography**
   - 8.3 **Radiation chemistry**
   - 8.31 Radiation polymerization
   - 8.32 Sulpho-chlorination of hydrocarbons
   - 8.33 Cross-linking of polymers by radiation
   - 8.34 Gamma radiation in the plastics industry
   - 8.35 Gamma radiation in the rubber industry
   - 8.36 Gamma radiation in the oil industry
   - 8.37 Gamma radiation in the pharmaceutical industry
   - 8.4 **Radioisotopes in Agriculture and Food Industry**
   - 8.41 Radiation sterilization
   - 8.42 Gamma Fields
   - 8.43 Radiation destruction of insects
   - 8.5 **Navigation aid with radioisotopes**
   - 8.51 Blind landing of aircraft
   - 8.52 Anti-collision warning
   - 8.53 Localization of lifeboats
9. **RADIOISOTOPES IN MEDICINE**
   - 9.1 **Radiotherapy**
   - 9.11 Co60 teletherapy of cancer
   - 9.12 Design of Co60 multikilocurie teletherapy facility
   - 9.2 **Diagnostics**
   - 9.21 Localization of brain tumours
   - 9.22 Body scanning
   - 9.3 **Nuclear medicine**
10. **PRODUCTION OF RADIOISOTOPES AND RADIATION SOURCES**
   - 10.1 **Pile production of radioisotopes**
   - 10.11 Activation
   - 10.12 Transmutation
   - 10.13 Production of Co60
   - 10.2 **" Hot " Laboratories and equipment**
   - 10.3 **Technology of strong multikilocurie gamma sources**
   - 10.4 **Source geometry and configuration**
   - 10.5 **Transport containers**
   - 10.6 **Manipulators**

D **Fourth cycle** (Reactor Technology)

1. **INTRODUCTION**
   - 1.1 Outline of Programme
   - 1.2 Historical Development
2. **Production of Uranium and Thorium**
   - 2.1 The fission theory
   - 2.2 Production of Uranium
   - 2.21 Exploration
   - 2.22 Mining
   - 2.23 Milling
   - 2.231 Uranium mills
   - 2.232 Processes
   - 2.24 Refining and Conversion
   - 2.241 Plant facilities
   - 2.242 Processes
   - 2.3 Isotopic enrichment
   - 2.31 Plant facilities
   - 2.32 Process theory
   - 2.33 Process Operations
   - 2.4 Production of Thorium
   - 2.41 Exploration
   - 2.42 Mining
   - 2.43 Refining and Conversion
3. **FUEL CYCLES**
   - 3.1 Solid Fuel Systems
   - 3.11 Fabrication Techniques
   - 3.12 Plant Facilities
   - 3.13 Recovery of Scrap Uranium
   - 3.2 Fluid Fuel Systems
   - 3.21 Fuel Preparation
   - 3.3 Reprocessing Spent Fuels
   - 3.31 Process Requirements
   - 3.4 Separation Processes
   - 3.41 Aqueous Processes
   - 3.42 Elevated Temperature Processes
   - 3.43 Cooling
   - 3.44 Two-Region Reactors
   - 3.45 Design Considerations
4. **REACTOR MATERIALS**
   - 4.1 Heavy Water
   - 4.2 Reactor Grade Graphite
   - 4.3 Beryllium
   - 4.4 Zirconium
5. **RESEARCH REACTORS**
   - 5.1 Basic Requirements
   - 5.11 Experimental capacity
   - 5.12 Neutron flux
   - 5.2 Research Reactor Types
6. **POWER REACTORS**
   - 6.1 Component and Design Considerations
   - 6.11 Nuclear Reactors and the Fission Process
   - 6.12 Regeneration and Breeding
   - 6.13 Moderation of Neutrons
   - 6.14 Neutron Balance
   - 6.15 Reactor Control
   - 6.2 Basic Reactor Types
   - 6.21 Principal Design Variables
   - 6.22 Major Types Being Developed
   - 6.3 Basic Power Reactor Types
   - 6.31 Pressurized Water
   - 6.32 Boiling Water
   - 6.33 Sodium Graphite
   - 6.34 Fast Breeder
   - 6.35 Aqueous Homogeneous
   - 6.36 Organic Moderated
   - 6.37 Liquid Metal Fuelled
   - 6.38 Gas Cooled
   - 6.39 Heavy Water
   - 6.4 Atomic Powered Merchant Ship
   - 6.5 Atomic Powered Aircraft and Spacecraft
   - 6.6 Military Power Reactor Development
   - 6.61 APPR-1
7. **RADIOACTIVE WASTE DISPOSAL**
   - 7.1 Wastes From Reactor Operation
   - 7.2 Separation Plant Wastes
   - 7.3 Dilution and Dispersal
   - 7.4 Concentration and Storage
   - 7.5 Disposal for the Long Range
8. **UTILIZATION OF FISSION PRODUCTS**△△△

# Institution's New Council Chamber

**Our photograph shows the Institution's new Council Chamber at Suite 2, 147, Victoria Street, London, S.W.1. The first Council Meeting in the new Chamber is to take place on September 8th, 1961. The Institution is rapidly acquiring a library of books on nuclear topics, to which Members may have access when calling at the Institution Offices.**



# New Members

## Elected 25th April, 1961

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| J. C. Barrett, Nova Scotia. | M | K. S. J. Dunlop, Gosport. | M | A. J. Jaggers, Birmingham. | AM | E. Parker, Chester. | M |
| L. F. Bowen, Coseley, Staffs. | AM | C. W. Edemenson, Middlesbrough. | M | H. A. Jones, Leicester. | AM | L. Stanton, Birmingham. | M |
| A. Browell, Essex. | M | T. F. Garty. Middlesex. | M | W. Miller, Lanarkshire. | AM | S. Visuvanathan, Illinois | M |
| W. E. Carpenter, Chalfont St. Peter. | AM | D. D. S. Fraser, Glasgow. | AM | F. D. Moles, Langley, Bucks. | M | R. C. Warner, Birmingham. | AM |
| B. A. C. Cheeseman, Slough. | AM | K. Gill, Coventry. | M | C. A. Norton, Cumberland. | M | P. Wheeler, Birmingham | AM |
| C. C. Doram, Cumberland, | M | L. E. Henson, Dumfriesshire. | AM | G. Novati, Bournemouth. | M | E.H. Wright, Cradley Heath. | M |

## Elected 31st May, 1961

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|---|---|---|---|---|---|---|---|
| J. Baird, Warlingham, Surrey. | M | H. Howorth, Todmordon. | AM | P. D. Marsden, Flixton. | AM | R. W. Skinner, Dorchester. | AM |
| S. U. Cunningham, Coatbridge. | AM | R. C. Horner, Derby | AM | E. G. M. Keith, Wotton-under-Edge. | M | W. E. T. Tonkinson, Blackheath. | AM |
| J. J. Daly, Ilford, Essex. | AM | G. F. Kirby, London. | M | J. T. Middleton, Erdington, Birmingham. | AM | F. B. True, Bradwell-on-Sea. | AM |
| P. J. Fretter, Wheathampstead | M | E. Lindsey Chelmsford | AM | T. Mitchell, Southampton. | AM | A. Weeks, Bedhampton, Havant. | M |
| G. A. Guy, Blackpool. | AM | J. W. Leedham, Donington. | AM | J. S. Nash, Newbury. | M | J. G. Wheatley, Gravesend. | JM |
| L. Harding, Basingstoke | AM | G. E. Mallett, Derby. | AM | R. G. Shakespeare, Dartford. | AM | A. W. Woodroffe, Cumberland. | M |

## Elected 5th June, 1961

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|---|---|---|---|---|---|---|---|
| W. J. Appleyard Millbank, S.W.1. | JM | J. G. Hart, Derby. | M | N. Knudsen, Stockton-on-Tees. | M | P. Rivkin, Southminster. | AM |
| D. Bryce, Putnoe, Bedford. | AM | D. K. Howie, Lanarkshire. | AM | F. J. Mockett, Caithness. | M | G. F. Sanger, Forest Gate, E.7. | AM |
| D. Carson, Cumberland. | AM | J. C. James, Staffs. | AM | I. Owen, Berkeley, Glos. | M | W. D. Thompson, Sydney, Australia. | M |
| D. P. Froud, Bracknell, Berks. | JM | G. B. Jones, Warwickshire. | AM | W. H. C. Pilling, Manchester. | M | R. W. Bryant, Lewisham. | AM |

*The United Kingdom has under construction several nuclear power reactors of the Calder Hall type. These reactors have natural uranium fuel, moderated by graphite and cooled by carbon dioxide gas. The Calder Hall and Chapelcross reactors have been operated successfully by the UKAEA for several years. It is likely that further reactors of an advanced Calder type, or new types based on the reactors under development at UKAEA establishments, will be added to the United Kingdom programme.*

*There is always some risk associated with the operation of industrial plant and from time to time accidents have occurred. In the operation of nuclear reactors there is a radiation risk, but in the absence of abnormal occurrences, the radiation shielding measures ensure that radiation levels to which members of the public may be exposed, are comparable to natural background and are within international recommended levels.*

*The need to give special consideration to nuclear power stations stems from a possible accident and an associated release of volatile radioactive material to the environment. The immediate hazard is the breathing of contaminated air and the less immediate but more widespread hazard is that associated with contaminated food and water.*

*Based on methods devised by Dr. F. Pasquill of the Meteorological Office, an estimate of the thyroid dose for a unit release of radioactive iodine under various weather conditions and at various distances from the reactor, has been made.*

# Siting of power reactors in the U.K.

by A. Quinton, MSc, FInstP

THE United Kingdom has under construction a series of power reactors for the production of electricity. These reactors are developed from Calder Hall operated by the UKAEA for the production primarily of plutonium but also electricity. The stations Bradwell, Berkeley, Hinkley Point, Hunterston, etc., will be operated by the Electricity Boards for the production of electricity at power levels ranging from 200 to 600 MW.

The fuel for these stations is natural uranium which contains 0.7 per cent. U-235, a fissile element. Using pure graphite as a moderator and reflector a neutron chain reaction can be maintained. The heat is extracted by circulating $CO_2$ and used for the production of high pressure steam to operate a turbine and produce electricity. The fission process and the absorption of neutrons in the uranium itself and other parts of the reactor produce radioactive isotopes which have a physical half life ranging from seconds to years. After some weeks of steady operation, the short-lived isotopes have attained equilibrium, *i.e.*, they decay as fast as they are produced; the amount of long-lived isotopes continues to increase with time but at a slower rate.

## Activity

In a power reactor (greater than 100 MW) the activity of the core during normal operation is of the order of 100m. curies of mixed radioisotopes emitting $\beta$ and $\gamma$ radiations as well as the $\gamma$ and $\eta$ radiations emitted in the fission process. Those parts of the reactor containing substantial quantities of radioisotopes are shielded by many feet of concrete so that the transmitted radiation to workers at the power station is small and within international recommendations. The public immediately outside the station site boundary receives very small doses comparable to natural background radiation.

## Coolant leaks

There is some unshielded activity associated with small leaks of coolant or induced activity in coolant air but the direct radiation hazard or the indirect hazard from deposited activity, contaminated air or agricultural products is small. As a precautionary measure regular monitoring for radioactivity is carried out around reactor sites of the United Kingdom Atomic Energy Authority; but there is no reason to expect normal running of nuclear power stations to cause a radiation hazard to members of the public and in the absence of abnormal occurrences there is no reason why nuclear power sites should not be chosen in the same way as ordinary power sites, *e.g.*, near centres of population where space and cooling water are available.

If, as a result of some accident serious plant failure or malfunction, volatile isotopes or radioactive dusts become airborne, there would be a multiple hazard from direct radiation due to cloud or deposited activity or from breathing contaminated air or eating or drinking contaminated food. The elements of particular hazard are those of moderate half life which are also important elements of the human metabolism.

Although all escaped radioelements present a hazard to the public, a study taking into account their volatility, chemical properties, the food chains in which they take part, and their physical half life, enables one to pick out for special study a few elements such as iodine, strontium, caesium, and of these iodine 1131 is the most important. This element is concentrated in the thyroid gland and if children drink iodine contaminated milk the thyroid may suffer radiation damage. Similarly strontium may produce radiation damage to the bone and caesium to the sensitive glands of the whole body. It is unlikely that doses not greater than 25 rem to the thyroid, 15 rem to the bone or 10 rem to the whole body will produce detectable clinical damage.

## Reactor Siting

There are important differences between the siting of reactors under development by UKAEA and the siting of reactors for economic production and distribution of power. The trying out of new ideas, the need for ancillary equipment already available on the Authority sites, the need to seek new information, all indicate a site remote from large populations. On the other hand, the building of reactors using established principles and procedures and designed solely

for power production, demands sites not too far removed from the consuming populations.

## Meteorological conditions

In a major accident there may be a release of $Q$ curies in a time $t$ sec at a height of $H$ metres. Although $H$ may equal the stack height it will be prudent to consider it to be a lower height determined by the break in containment. At a distance $x$ metres downwind at ground level the concentration of contaminant ($x$ c/m$^3$) will be a function of the windspeed ($u$ m/s), the height of release ($H$ m) as well as $Q$, $t$ and the meteorological conditions. These will determine the horizontal ($h$) and the lateral spread ($\theta$). It is convenient to think in terms of the time integral $\int X\,dt$ since its product with the breathing rate ($C$.sec/m$^3$ $\times$ m$^3$/sec) gives the total activity breathed in by the individual at a distance $x$ metres. To a rough approximation for small values of $x$ the activity breathed in is (i) inversely proportional to $x^2$, (ii) inversely proportional to $u$.

## Horizontal spread

The horizontal spread is a function of the variability in wind direction. The vertical spread is a function of the stability of the atmosphere. When there is a temperature inversion with height the stability is high and the vertical spread low: when there is a large lapse rate the stability is low and the vertical spread greater. It is possible for the lower atmosphere to be turbulent but to have above it a well marked inversion layer limiting further vertical spread. To a first approximation making use of curves prepared by the Meteorological Office, it is possible to select a given weather category and estimate the time integral $\int X\,dt$ in terms of $Q$, $u$, $h$ and $\theta$.

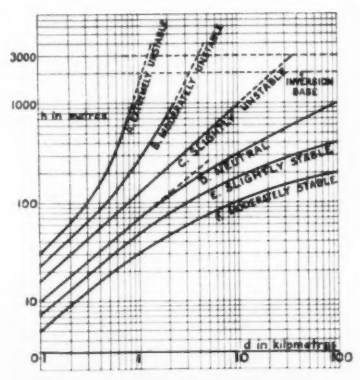



**Fig. 1—Estimates of vertical spread $h$**

Meteorological conditions are very variable in the U.K., and for any one site it is not possible to assume that any given weather condition will prevail. It is not possible for example to site a station near to a large town on the basis that the prevailing wind is away from the town. In this article two weather categories out of the six specified by F. Pasquill (Met. Office)* are selected to illustrate the relevance of meteorological conditions to reactor siting:

Category D—Neutral weather, lapse rate near zero, windspeed 5$^m$/s.

Category F—Moderately stable, windspeed 2$^m$/s.

On about 50 per cent. of occasions weather in the U.K. is of Category D and for about 20 per cent. Category F.

It is necessary at any power reactor site to have instruments to record windspeed and direction and to have good liaison with the Meteorological Office so that a quick estimate can be made of ground concentration downwind following an accidental release. The meteorological information will also help in the effective deployment of health physics vans and in early warnings to local authorities. However, site selection is dependent mainly on the average weather conditions over the lifetime of the station with some consideration to the worst conditions but it is unrealistic to assume that all the possible factors decreasing the dilution of the cloud act at the same time.

Weather conditions quite clearly affect the inhalation hazard to an individual at different distances $x$ metres from the accident but except in that sense there is no reason to choose one site instead of another on meteorological grounds alone.

## Topographical considerations

In deciding on the suitability of an individual nuclear reactor site the local topography is important. The presence, for example, of a land-locked inhabited valley where air concentrations or depositions cannot be expected to follow the normal dilution pattern for a flat terrain may preclude use of the site. Extensive elevated land masses may distort the local air flow and sites on coasts or large estuaries are always subject to special influences which need to be studied for the individual site.

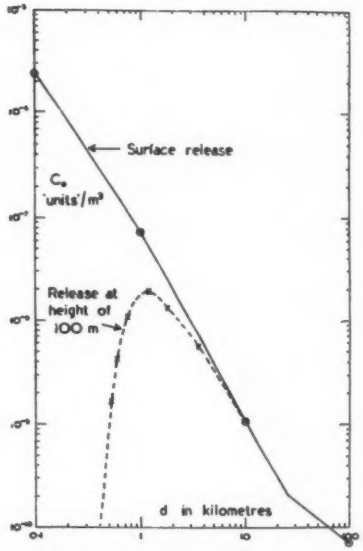



**Fig. 2—Example of calculation of axial concentration for source strength 1 'unit'/m**

When a decision has been reached to regard several possible sites as suitable, it is still important to take into account all the individual features of the sites so that the final one chosen is the best. These considerations would include disturbance to local amenities such as national parks, seaside resorts, bird sanctuaries and also local services such as schools, hospitals, water reservoirs. A local enquiry is useful to allow the various conflicting influences to be made known and a balanced judgment made.

## Meteorological aspects

It is important to seek a correlation between the release of a dust or volatile contaminant, the meteorological conditions actually or likely to prevail and the estimated dose to anyone breathing the contaminant. In the U.K. meteorological conditions are very variable and siting studies based on prevailing winds and times of year have proved unrewarding.

Pasquill following up the work of Sutton, has made an estimate of the dispersion of windborne material under selected weather categories

*Dr. F. Pasquill " The Estimation of the Dispersion of Windborne Material "—*Meteorological Magazine*, February, 1961, page 33.

of which moderately stable (F) and neutral (D) are made use of in this paper to estimate cloud dosage ($^{c.sec}/m^3$) for a unit release of iodine I131 and an estimated child thyroid dose. The results are shown in Tables 1 and 2.

The basis law is:

$$Co \propto \frac{1}{ud\theta h}$$

where

$Co$ = peak concentration ($^{c.sec}/m^3$) on the air-flow axis.

$d$ = range in Km.

$\theta$ = horizontal spread in degrees.

$h$ = vertical spread in metres.

In Fig. 1 vertical spread $h$ is plotted against range $d$ for all weather categories including D and F. The neutral category D is assumed for overcast conditions day and night. The moderately stable category F is assumed for light winds and a clear night.

In Fig. 2 the cloud dosage for a unit release is plotted against range $d$ for two heights of release, ground and 100 m. It will be noticed that beyond 1 km the cloud dosage is much the same in both cases.

In the event of an actual release the likely concentration for a unit release at a given range can be estimated and from a ground measurement the stack release calculated. It is rather a different problem to predict the effect of a release at some time in the future but estimates based on D and F weather categories give the likely range of concentration and doses.

It should always be remembered that the doses actually received may be reduced by "avoiding action" such as physical evacuation or medical measures. If the child dose figures are divided by 5 the adult figures may be obtained. For an average population distribution, 8 per cent. (0-4 yrs), 8 per cent. (5-9 yrs), 8 per cent (9-14 yrs.) 8 per cent. (15-19 yrs) and 68 per cent. adult, the mean dose to the whole population may be obtained by multiplying the child figure by 0·328.

TABLE 1

*1 curie $I^{131}$ release* — *Category F* — *Moderately stable (2 m/s)*

| Range | Mean range | Cloud dosage | Mean dose to child (0-4 years) averaged over 30° sector |
|---|---|---|---|
| Miles | Km | curies sec/m³ | rem |
| 1– 2 | 2·5 | $2{\cdot}9\times10^{-5}$ | $580\times10^{-4}$ |
| 2– 3 | 4·0 | $1{\cdot}3\times10^{-5}$ | $267\times10^{-4}$ |
| 3– 4 | 5·7 | $8{\cdot}4\times10^{-6}$ | $174\times10^{-4}$ |
| 4– 5 | 7·3 | $6{\cdot}2\times10^{-6}$ | $128\times10^{-4}$ |
| 5– 6 | 8·8 | $4{\cdot}8\times10^{-6}$ | $98\times10^{-4}$ |
| 6– 7 | 10·4 | $4{\cdot}0\times10^{-6}$ | $81\times10^{-4}$ |
| 7– 8 | 12·0 | $3{\cdot}4\times10^{-6}$ | $70\times10^{-4}$ |
| 8– 9 | 13·6 | $2{\cdot}9\times10^{-6}$ | $58\times10^{-4}$ |
| 9–10 | 15·1 | $2.5\times10^{-6}$ | $52\times10^{-4}$ |
| 10–11 | 16·7 | $2{\cdot}3\times10^{-6}$ | $47\times10^{-4}$ |
| 11–12 | 18·3 | $2{\cdot}1\times10^{-6}$ | $44\times10^{-4}$ |

TABLE 2

*1 curie $I^{131}$ release* — *Category D* — *Neutral weather (5 m/s)*

| Range | Mean range | Cloud dosage | Mean dose to child (0-4 years) averaged over 30° sector |
|---|---|---|---|
| Miles | Km | curies sec/m³ | rem |
| 1– 2 | 2·5 | $3{\cdot}85\times10^{-6}$ | $80\times10^{-4}$ |
| 2– 3 | 4·0 | $1{\cdot}68\times10^{-6}$ | $35\times10^{-4}$ |
| 3– 4 | 5·7 | $9{\cdot}70\times10^{-7}$ | $20{\cdot}3\times10^{-4}$ |
| 4– 5 | 7·3 | $6{\cdot}60\times10^{-7}$ | $13{\cdot}7\times10^{-4}$ |
| 5– 6 | 8·8 | $4{\cdot}70\times10^{-7}$ | $9{\cdot}7\times10^{-4}$ |
| 6– 7 | 10·4 | $3{\cdot}50\times10^{-7}$ | $7{\cdot}2\times10^{-4}$ |
| 7– 8 | 12·0 | $2{\cdot}82\times10^{-7}$ | $5{\cdot}8\times10^{-4}$ |
| 8– 9 | 13·6 | $2{\cdot}60\times10^{-7}$ | $5{\cdot}4\times10^{-4}$ |
| 9–10 | 15·1 | $1{\cdot}92\times10^{-7}$ | $3{\cdot}9\times10^{-4}$ |
| 10–11 | 16·7 | $1{\cdot}65\times10^{-7}$ | $3{\cdot}4\times10^{-4}$ |
| 11–12 | 18·3 | $1{\cdot}45\times10^{-7}$ | $3{\cdot}0\times10^{-4}$ |

Tables 1 and 2 enable a comparison to be made between the two selected weather categories. Very approximately 1 curie $I^{131}$ under moderately stable weather produces a similar concentration to ten curie under average weather.

## Reactor siting

Experience has shown that progress in the development of sources of power entails damage to property and some loss of life, either in small accidents associated with routine working, or bigger accidents of much lower probability. Experience has also demonstrated that certain accidents can be avoided by anticipating the various things that can go wrong and taking measures to prevent them or mitigate their effects. It is probable that a bigger safety effort has been put into the development of

nuclear power than any other industry but it would be foolish to suggest that no major accident will occur and, of course, minor accidents will occur.

The only major accident in the U.K. up to the present is the Windscale incident (October, 1957) when over $10^4$ curies of radioiodine was released from a 400 ft stack but no radiation casualties were caused.

It is accepted that all nuclear power reactors should include full safety precautions including instrumentation, shut-down devices, containment and clean-up systems so that there are at least two lines of defence to meet possible accidents.

For distances up to a mile from the reactor, it is prudent to continue the policy of keeping the numbers of members of the public small. This condition is unlikely to prove a handicap in the economic production of power and it does enable emergency measures, including evacuation, to cope with those people at greatest hazard.

### *Acknowledgement*

The illustrations in this article have been taken from the February, 1961 issue of the *Meteorological Magazine* and are reproduced by the kind permission of the Controller of HM Stationery Office. △△△

# Trade Literature Received

English Electric have issued a folder giving brief details of the comprehensive range of Magnetrons, designed and manufactured by the English Electric Valve Co., Ltd. Pages 1-4 list the types in order of code numbers; page 5 lists the service type numbers; and pages 6 and 7 the ascending nominal frequencies. Except for two types where mechanical tuning is detailed, all these valves oscillate at a fixed frequency within the particular range quoted. For some a separate magnet is required. Those fitted with an integral permanent magnet are specified as " packaged." Full technical information can be attained on request. A very useful Valve Replacement Index has also been published by English Electric.

The physical type Dissolved Oxygen Analysing Meter manufactured by Cambridge Instrument Co., is described in a new publication, List 148/2x. This physical type meter gives warning of corrosive concentrations of oxygen in smaller boiler plants employing mechanical deaerators. After supplying some general information on the instruments the publication deals with sampling equipment, the karathometer, the analysing unit and ranges and recorders.

Two more publications of Cambridge Instrument Co. List 143/1 deals briefly, but comprehensively, with recording counters, describing their functions, applications and range. List 25/1 provides extensive ininformation on vapour pressure thermometers. Its contents include notes on choosing a suitable VP thermometer standard specification, standard instrument pattens, alternatives, and accessories, temperature control pointers and contact types, mounting details, weights, prices and delivery. The brochure is well illustrated.

Graduate training at the Rugby Centre of Associated Electrical Industries, Ltd. is the subject of a fully illustrated brochure just issued by the company. Graduate training in AEI based at Rugby offers scope in the electronic apparatus, heavy plant, and motor and control gear divisions; also in the AEI Lamp and Lighting Company and AEI-Birlec, Ltd. Talks, films and discussions introduce the young graduate to industry in general and AEI in particular. He then begins his training and most of the book is devoted to the various branches of the engineering industry open to him. Leisure pursuits and opportunities offered upon completion of training are not overlooked.

The third edition of Philips' abridged catalogue on nuclear equipment includes a number of new products. These are built either in the form of modular units or as fully integrated instruments. Subjects covered in this catalogue include integrated instruments, spectrometry, portable neutron generators, functional units, radiation detectors, universal lead castles, low background assemblies, monitors and dosimeters, radioactive sources for calibration purposes, radioactive isotopes for medicine, research and industry and a survey of typenumbers.

Johnson Matthey have issued a new edition of their booklet 1760, Spectrographically Standardized Substances. The metallic impurity contents, as detected spectrographically, are now uniformly stated in parts per million and higher purities than previously offered are quoted for many products.

A data sheet is available from Stereotronics Corporation on their Stereo-Television Kit, which was especially designed for the manipulation of radio-active material by means of closed-circuit TV. The Stereotronics System consisting of three devices (Stereo-Captor, Stereo-Screen and Stereo-Glasses) converts any closed circuit TV equipment to a three-dimensional picture. This invention can be applied to viewing dangerous materials and observation of plant and laboratory work techniques, among others.

" It is an axiom of present day industrial technology that progress in virtually all fields is dependent upon the availability of improved materials of construction. To meet the challenge presented by this necessity, a number of important new ceramic materials have been developed, materials which, by virtue of their exceptional qualities of hardness and mechanical strength and outstanding properties of high resistivity and thermal conductivity, are revolutionizing engineering design philosophy." Thus Lodge Plugs, Ltd. introduce their foremost ceramic, Sintox. Detailed information is supplied on all aspects of the material, including manufacturing methods, chemical compositions, properties, applications, etc. An abbreviated 8-page version of the brochure is available to engineering designers, research and development engineers, etc.

A colourful leaflet on the new FHP Servo Motor and Motor Generator has recently been published by Evershed and Vignoles, Ltd. This details briefly the wide range of Evershed motors now available, including a.c. and d.c. servo motors and motor generators; special purpose meters; tacho generators; gearheads and torque transmission units; and amplifiers and power units.

The result of further research and development into industrial cooling problems is to be seen in a leaflet issued by Head, Wrightson & Co., Ltd. One of the latest developments is the Low Head series of Towers, specially designed for small industrial duties, including air conditioning and refrigeration. Series 2-4 of the Cooling Towers are described and illustrated together with a note on Polygrid packing—a new high-efficiency non-corrosive plastic packing.

We have received notice that a new catalogue of radiation protection materials equipment and accessories of interest to anyone concerned with gamma or X-rays is now available from Research & Control Instruments, Ltd. Materials are listed suitable for every type of laboratory, production, or site work and the advisory service offered by the firm is described.

New and established grades of silicone rubber are described in a booklet entitled " Silastomer and other MS Silicone Rubbers—a summary of the most important grades " issued by Midland Silicone, Ltd. The new rubbers include general purpose grades, low compression set grades and extremely low temperature grades. △△△

# Radiation and the human body

*By Dr. S Schmidt, Professor of Radiation Therapy*

**This article consists of the text of a lecture delivered in June this year at the Centro Italiano Ricerche Elettroniche Nucleari in Rome. The author illustrates the potential dangers and harmful effects of radiation and stresses the importance of collaboration between the industry, the medical profession, biologists and physicists. Emphasis is laid on the importance of objective decisions, regardless of political or economic considerations, when health problems concerning nuclear energy are under examination.**

AT present the exact radiation doses required to produce biological changes are still unknown. If only for this reason it is essential that the radiobiologists should not only guarantee but actually prove the absolute safety of any project which involves the slightest risk of nuclear radiation. This should be done before the construction of nuclear reactors or the setting up of any nuclear radiation equipment as well as before the authorization of atomic bomb tests or the disposal of radioactive waste.

It may rightly be claimed that this is often a most difficult task, but to realize its importance we have only to remember the pioneers in the development of Roentgen's X-ray equipment who were unfamiliar with the dangers of radiation and suffered serious injuries. In all 197 workers lost their hands in this work. Another sobering example is the high incidence of lung cancer among workers in the lead and uranium mines in Joachimstal.

According to Prof. Segal, even *the normal rays surrounding us* (cosmic, terrestrial and those resulting from the natural radioactivity of the human body) which are equal to about 3r in 30 years can result in the formation of cancer cells in the body. There is little to be done against this "background radiation." However, we can protect ourselves against *artificially produced rays* such as result from the use of X-ray equipment, radium preparations and treatment with radioactive isotopes (up to about 10r in 30 years). Special protective measures must be taken to prevent an increase in overall radioactivity since there is no "threshold value" and the effect of any radiation spells potential danger (report from Prof. Rajewski, Frankfurt, 1.10.1960). Prof. Witte, Göttingen, reports on the effects of radiation as follows: "Even the smallest possible dose of X-rays, the 'photon' can produce definitely harmful effects. Animal experiments have shown that in 90 per cent. of the cases of radiation damage the harmful effect did not manifest itself in specific symptoms but merely in a reduced life-span of the irradiated animals."

## Ionizing rays

Radiation damage to cells is mainly caused by the ionizing rays, resulting in the formation of free radicals which in turn lead to the destruction of the ribonucleic acids, breaking up of the polynucletide chains, the formation of cell toxins, disruption of ferment action and the permeability of the cell membranes. Minute doses of radiation may suffice to bring about point mutations which in turn lead to vitality mutations.

For patients receiving radiotherapy and people working with radioactive materials radiation exposure can be reduced by development of improved technical equipment using X-ray tube filters, strong radiators, contrast magnifiers, etc. and possibly incorporating a radiometer in each generator (this problem has been solved ideally in the case of the Cobaltron 2000).

A reduction must be made in the number of fluoroscopies (up to 10r) in favour of more radiographs (up to 1r); the banning of X-rays for pregnant mothers and children, the introduction of a "radiation passport" and the use of non-harmful contrast media such as Abrodil are also desirable considering the number of cancers caused by Thorotrast in the course of the last 10 years. The U.N. have rightly forbidden the irradiation of foodstuffs as this partially destroys amino acids and the vitamins and fats almost completely (Prof. Visco, Rome). There is a need for more effective protective measures such as lead screening, lead-lined walls, baryto-concrete, gabaryt stone, lead protection of the gonads, lead finger-stalls for dental radiographers. Radium carriers should never be handled!

People whose work brings them in contact with radioactive materials should always wear a radio-protection disc to measure the dose received.

## Diet

Great importance should be attached to diet which should provide calories and vital substances and also regulate the ions of hydrogen.

The decisive factor however, is not the acid and the basal equilibrium of the food itself, but whether it continuously controls and regulates the concentration of hydrogen ions in the body. This task is performed

by the lactic acid fermentation products. Daily intake of biological lactic acid fermentation products (dextrorotatory), such as Viscolacticum (Dr. Kuhl, Rheine, reduces the lactic acid in the tissues, which is abnormally high during general disorders of the tissues, towards the " neutral point." As the acid passes into the blood, the alkaline reaction on the blood is likewise brought nearer to normal, at least where ferment reaction is possible.

" Mould diets " should also be considered. According to Dr. Kuhl, 250 mg of shredded wheat are broken up and mixed with 50 mg of water. The mixture is placed in an incubator or in a warm place, up to 25°C., for 5 days after which the substance is chopped up and mixed with curd cheese, honey and fruit. Mould is an excellent source of vital substances and trace elements. According to tests carried out by Dr. Kuhl sensitivity to radiation is reduced. A daily intake of 250 mg of " Schimmel-Müsli " (mould preserve, mould cake, mould cheese) affords extensive protection against the harmful effects of radiation.

## Animal experiments

Successful demonstrations in animal experiments have shown that the administration of algae, previously irradiated alive (600 r), had a radioprotective effect.

The diet should include yoghourt or curd cheese (about 500 gm daily) with approx. 200 gm cauliflower daily and yeast (brewers' yeast is especially rich in glutathione). Beetroot is another prophylactic, the recommended daily consumption being either about 30 gm in powder form (Fa.Hefa) or the juice of 1 kilo raw beetroot. *Beta vulgaris* has proved to be particularly effective in bringing about improvements in cases of cancer and leukaemia. The anthocyaneins present in beetroot regulate ferment action, especially respiration; this has been observed in animal experiments. Mention must also be made of chemical preparations such as Antitron. Antitron which detoxicates the radicals and the hydrogen peroxide formations has proved its value as a chemical radioprotector (5-10 tablets $\frac{1}{2}$ hr before radiation) (Prof. Joklik, Fortschritte in der Strahlentherapie, Archiv Geschwulstkrankheiten 1960, Vol. 16 H3.). Other useful substances include Gelee Royale, Modenium (Hefa) of Roygel (Glutanchemie). Smooth functioning of the liver and the intestines must be ensured. For this purpose liver and coli preparations are indicated. Adequate holidays are another " must!"

(*Above*) **Condition of the hands of a radiography sister employed in a dental clinic who had for many years been holding dental films**

(*Right*) **Bone condition of the thumbs of the same sister**

## Biological preparations

Patients should receive the diet indicated above and in addition one injection each of liver-pituitary-diencephalon both before and immediately after irradiation. It is not possible here to name individual preparations but some methods of treatment which have proved effective can be indicated. Biological preparations are valuable in that they accelerate the metabolic processes and normalize the cellular function by providing sound protostages of desoxyribose-nucleic acid. A combination of biological and chemical preparations (with detoxicating effect) offers a more promising method of treatment. Only shortly beforehand is it possible to give total Foetus (Emb 112 Hefa), or Tissula Neo (Hefa) or bone-marrow cells (this is a case of genuine cell transplantation), lysates, bone-marrow lysates (Hefa) or cytoplasmatic organic preparations bone marrow (Vitorgan), or to carry out a Bogomolets treatment. At the same time vitamin preparations such as Styptobion (Merck). Modenium (Hefa) or a royal jelly preparation can be prescribed before and after irradiation. A blood cleansing process according to Wehrli may also be considered. In addition, chemical radioprotective preparations should be prescribed.

The treatment indicated is especially recommended in the irradiation of cancer and tumour patients. As a result, healthy tissues are afforded a greater degree of protection, the pathogenic effect of the ionizing rays is reduced and the tumour may be bombarded with a higher dose. It is now recognized that the " radiation hangover " following irradiation often has an unfavourable effect on the patient with regard to further treatment. To avoid, as far as possible, skin reactions of irradiated patients, the areas of the skin to be exposed should be treated before radiation, with cortisone preparations (antiphlogistic); further protective measures should include the administration of vitamin A (to control epithelial disorders), B Corti-Flexiole (Dr. Mann) and cod liver oil or liver tissue ointments such as Hepaderm (Hefa). Multiform harmful effects make multiform therapy essential.

## Skin effects

X-ray or radium treatment can have harmful effects on the skin similar to those resulting from atom bomb explosions.

Such cases have been treated with Bogomolets-Serum (Anacyton (Hefa)), Fibronorm Hefa, SAC Berna (Glutanchemie); small quantities are

injected around the ulcers (up to about 0·5 cc once weekly). Impletol swellings did not produce the same results. After the Bogomolets serum the lysates of Firma Hefa, Braglia, of bone marrow, liver, diencephalon and adrenal glands, Tissula Neo and chick embryo Emb 112 (Hefa) were administered. The application of Dilution Skin 5 as a compress to the radiation ulcers, stimulated epithelization and the radiation damage healed.

### Pain relief

More recently, rapid freedom from pain in X-ray and radium burns has been achieved with galvano-faradic currents and the neo-dynator, using epilation as additional therapy. Galvano-faradic currents have a pain-relieving and hyperaemic effect (physical impletol therapy).

In one case, a 42 year old woman developed a half-crown sized ulcer about 3 cm deep, over the M. Sternocleido mastoeideus near the sheath of the Carotis after radium treatment for cancer of the larynx 10 years previously. A lobular plastic operation was unsuccessful and a fatal erosion haemorrhage was expected. Following Bogomolets swellings in the wound area and administration of lysates of bone-marrow, adrenal gland and liver, the wound healed. The application of gauze compresses with skin dilution 5 proved particularly effective and epithelization was accelerated.

In another case a 53 year old man was given radiation treatment for malignant melanoma of the sole of the right foot. He had received about 25,000 r and was suffering from a serious nutritional disorder. Amputation was considered. The wound developed into a running sore about 4 cm wide and 2 cm deep and was treated with Bogomolets swellings (3 or 4 around the ulcer every 3 or 4 days, about 5 times). Immediately after the first injection, the unbearable pains were alleviated. In addition lysates were prescribed. The liver ointment (Hefa) gave good results and the patient can now walk for hours without ill effects.

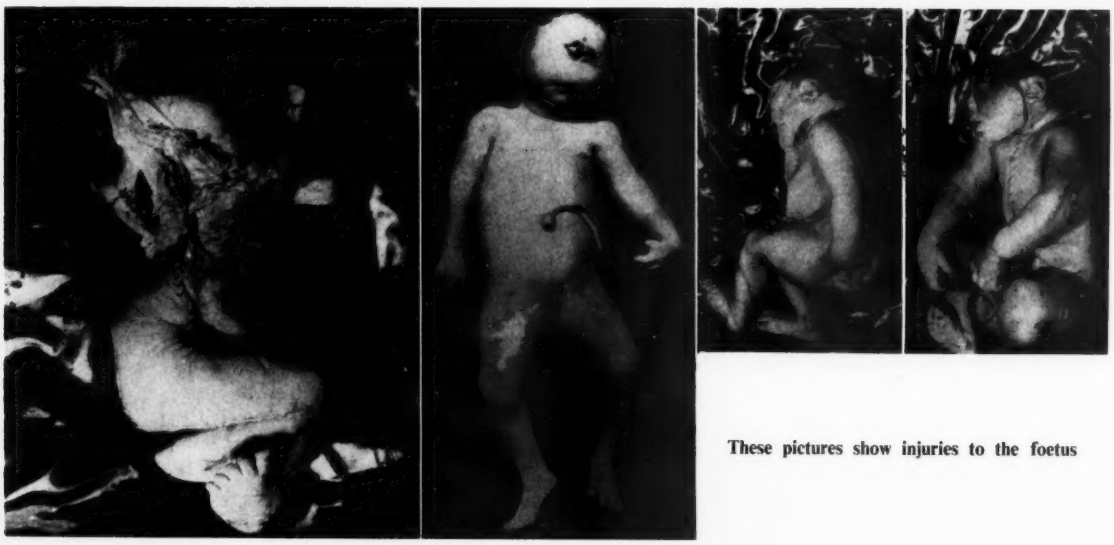
**Woman with an ulcer near the sheath of the Carotis, (*left*) before treatment and (*right*) after treatment**

### Serious position

As a prophylactic measure it is essential to minimize radiation from atomic reactors and atom bomb tests; also the quantities of atomic waste and world-wide radioactive contamination should be reduced. The seriousness of the position is made very clear by Prof. Pauling, U.S.A., who claims that the atom bomb tests carried out so far will cause the premature death of about 2·5m. people.

### Many deaths

Further proof is provided by the report of Prof. Kaplan, University of Dalhousie, according to which the strontium-90 resulting from atom bomb tests will cause the death of about 10,000 people from leukaemia or cancer of the bone within the next 40 years. The UKAEA has found that the content of Sr90 in the bones of British children has doubled since



**These pictures show injuries to the foetus**

1958. Before 1950 it was believed that 1,000 r were needed for the formation of cancer in embryos, in 1955 this was reduced to 200 r and now the limit has been put as low as 2 r. It is at present thought that induced doubling of the mutation rate occurs at 40 r so it is essential to oppose any increase in the total load of radiation if a rise in the number of feeble-minded, deformed and mentally defective people is to be avoided. Particular importance must be attached to recessive genetic damage as this may be hidden at present and cause malformations in future generations. For this reason, Prof. Mainx of Vienna has claimed that, from a genetic point of view, the dose of the reproductive organs should be limited to a maximum of 3-4 r/generation.

### Disease resistance

Lowered resistance to infectious diseases is so far the most minor manifestation of genetic damage. Direct damage represents a lethal effect. The children of Hiroshima should be a constant warning to exercise still greater care.

Radioactive spa waters are being continually mentioned to play down the danger. However these springs only radiate for minutes or, at most, hours and are rarely absorbed. On the other hand, Sr90 for instance radiates for 28 years and is absorbed.

Another warning sign is presented by the hot granules resulting from atom bomb tests in the air. They are highly radioactive and have a diameter of about 0·001-0·002 mm.

### Hot-grain distribution

The average distribution of these hot grains is 1/500 cu.m air. (Man breaths 25 cu.m air/day which means 1 hot grain every 20 days). Where such a hot granule lands, it destroys 5-6 healthy cells which, in case of low body resistance, can lead to cancer. In addition, atomic explosions cause not only meteorological changes by their effect on the electricity of the air (Prof. Beyer, Chicago), but also earth tremors to a depth of 70 km (Prof. Pfeiffer, New Jersey).

It should also be remembered that the radioactive fall-out from atom bomb tests circles the earth for a number of years and is then slowly deposited. The examinations of the Geobotanische Institute Rübel near Zürich in 1901 showed that dust from the Sahara was deposited in the Alpine region at the rate of 11 tons /sq.km and that even in Denmark the rate was still 1 ton/sq.km. It is well to bear in mind the potential danger if this dust should become radioactive.

### Additional lime

Farmers can take the precaution of putting more lime on their land since plants take up less Sr when there is sufficient calcium available.

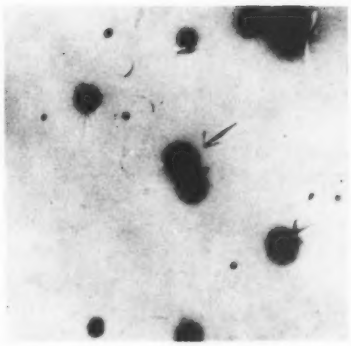
Another great danger is represented by the atomic reactors with their radioactive waste gases and refuse. The American Atomic Commission recommends a safety zone of 30 km. The occupational hazard of work in atomic reactors is demonstrated by the advice to reactor employees not to marry each other in view of possible genetic radiation injuries.

The building of atomic reactors should be governed by close collaboration of biologists, doctors and physicists in order to avoid disappointments later on. It is further absolutely essential for the disposal of atomic waste to be controlled on an international level. Radioactive waste must not be dumped into the sea or into rivers (Winfrith: Armelkanal). Even at the present time, the amount of highly radioactive waste is 10,000 ton/annum. Much is made of the great dilution that takes place in the sea. This means taking a purely physical view whilst ignoring the biological aspect. In this instance it is the accumulation in marine life (plankton) that represents the primary danger. Examinations of the egg-yolks of sea birds at the atomic reactor at Hanford showed an increase of radioactivity compared with river water of 1½m. An international agreement concerning the disposal of atomic waste would be a genuine prophylactic measure.

### Waste disposal

Recently there has been much talk of dumping waste in the Mediterranean but there are safer methods of disposal *e.g.* in abandoned mines, freezing-in in the polar regions and utilization after nuclear processing.

The radioactive substances are a thousand million times more dangerous. Human absorption of radioactive substances through plankton, fish, etc. constitutes one of the major



**Hot grains**

hazards resulting from atomic activities. Maximum tolerance values must be viewed from both the physical and the biological angles. From the genetic point of view there can be no threshold value. So the aim must be to avoid increased radiation. Radioactive refuse must be kept under constant supervision in a safe place.

### International action

There is a most pressing need for international regulations on the dumping of radioactive wastes in the sea. The container material at present used is subject to corrosion and entirely permeable. Furthermore, there is constant intermixing of waters from the lower depths with that of the layers nearer the surface. Other considerations are whether the sea is inland, such as the Baltic or the Mediterranean and the extent of fishing. Dilution in inland seas is likely to be insufficient.

Dr. Jansen together with Prof. Jaag, Zürich, have developed a method of dumping liquid radioactive waste in controllable basins containing growing *Characeae*. The algae take up radioactive substances and can afterwards be burnt, or placed in special barytes casks and stored in bunkers.

The first consequence of an irresponsible disposal of atomic waste should be a rise in the incidence of cancer and leukaemia. Physicians, physicists, biologists and industry must speed up the search for a safe method of disposing of radioactive waste.

Atomic energy used for the benefit of mankind can mean a happy future for all, but only if due regard is paid to its dangers and effects on public health. △△△

# Book Reviews

**Steels for Reactor Pressure Circuits.** Published by The Iron and Steel Institute, 65*s*.

This is Special Report No. 69 issued by The Iron and Steel Institute and consists of a full record of the proceedings of a symposium organized in London on November 30-December 2, 1960 by The Iron and Steel Institute for the British Nuclear Energy Conference. Representing as it does a comprehensive collection of the latest knowledge of steels for the nuclear industry this book is essential for the nuclear engineer and designer. The book has been classified into sections under the following headings: High-temperature properties; Corrosion; Fabrication aspects; Irradiation effects; Steels for future reactors. In addition there is an introductory lecture by Sir Leonard Owen and a section devoted to general discussion of all the papers. Well-designed and adequately illustrated, this book has been published at a very reasonable price.

**Nuclear Pulse Spectrometry,** by Robert L. Chase. Published by McGraw-Hill, 66*s*.

Chapter one of Mr. Chase's book deals with types of radiations, their characteristics, and with details of counting devices used for detection and assessment. Chapter two covers treatment of linear amplifiers, their differentiation devices, amplifications, loops, overload and noise. Other chapters deal with types of pulse-height analysers. A discussion follows on the time analyser then a multi-dimensional analysis is given and counting losses. In the electronic systems and circuits are counter and ionization chambers, GM counters, proportional counters, scintillation counters, details of two spectrometric devices based on relations between pulse-amplitude and pulse-detection and incident particle energy. There is excellent coverage of analogue-to-digital conversion schemes to multi-channel analysers and methods of applying corrections for counting errors. Mr. Chase caters for technicians who wish to use his book as a working reference. He omits mathematics of electronic circuits, their characteristics and concentrates on practical aspects, giving hints on fault diagnosis and on repairs to spectrometric devices. This information is generalized and will be valuable to those interested and working on radar and computers. Each chapter has references to literature sources—adding to the book's appeal. The many diagrams are clear and not elaborate. The book's style is pleasing, the sentences being short, to the point, with text arrangement being logical and understandable. F.R.P.

**The Theory of Thermal Stresses** by B. A. Boley and J. H. Weiner. Published by Wiley & Sons, New York, 1960. 586 pp. Price £6 4*s*.

The current rate of output of solutions to problems in applied mathematics of technological interest is so large that the compilation of a text-book presents a formidable problem in providing both basic principles for the advanced student and a useful survey of present knowledge for the experienced research worker. In this book a determined attempt has been made to satisfy both sets of requirements in the field of thermoelasticity and thermoplasticity. About 50 per cent. of the space is devoted to the basic principles of thermoelasticity and the remainder to an examination of some typical problems of the non-elastic consequences of thermal stresses in real materials. The basic equations of thermoelasticity are developed in detail starting from the thermodynamical description of non-uniform, continuous systems. The heat transfer section is devoted principally to the conduction mode and is developed along traditional lines to give the conventional steady and unsteady solutions of the heat conduction equation. The graduate applied mathematician or the engineer with a strong mathematical background should find these sections of immense value both in providing familiar equations from his undergraduate studies and in stimulating thought about the limitations of these equations. The discussion of the importance of the mechanical coupling terms in the heat conduction equation provides a good example of such a possible limitation. The basic application of the thermoelastic equations and the heat conduction equations to real structures focuses attention on beams, stresses, frames and built-up structures and some simple plate problems. A further chapter considers thermoelastic stability of beam-columns and plates. The last quarter of the book is devoted to the behaviour of systems which are stressed thermally but in which the deformations are related to the stresses by non-elastic laws. Examples of such laws are the linear visco-elastic group of laws (which simulate many aspects of secondary creep behaviour) and the time independent yielding laws of von Mises and Tresca. Applications are made in particular to creep buckling and to the residual stresses left in plates and cylinders after a thermal transient into a yielding state. The design of economic reactor cores is governed to a large extent by our degree of confidence in using materials in the creep and yield conditions and the last section is a good illustration of the types of thinking which are going into the design of nuclear reactor cores at the present time. The book will be of great value to research workers as a reference book and to graduate students who are taking up the subject of thermal stresses for the first tme. The authors have produced a standard work in this rapidly developing field.

R.G.A.

**Atomic Energy Waste, its Nature, Use and Disposal.** Edited by E. Glueckauf. Published by Butterworth. 420 pp. Price 95*s*.

It is very doubtful whether, in the annals of technology, a knowledge of the hazards associated with any particular discovery or invention has ever seriously impeded its progress or development. Atomic energy can be no exception here. In fact, right from the time when the whole-scale handling of radioactive materials came to be an everyday and routine operation, scientists and engineers have been keenly aware of the dangers of the waste-products and the difficulties inherent in their disposal. These problems, great as they were, have not been considered insuperable, and considerable ingenuity has been dedicated to the working out of different methods of rendering relatively harmless the effluents from nuclear energy establishments. In Britain, the storage and treatment of waste products represents only about 0·2 per cent. of the total costs of nuclear power. Casualties due to radiation exposure have, in Britain, been negligible compared with those from conventional industrial accidents. There are, basically, three problems requiring simultaneous and parallel approaches—the safety of the personnel, the disposal of radioactive wastes, and the utilization of wastes so as to render them less of an embarassment. This is the background against which this book has to be assessed. The first part of this volume, " Fission and fission products," by G. N. Walton, is almost a book in its own right. It is an admirably lucid and concise account of the discovery of fission, cause and types of fission, neutrons and fission energy, mass and charge distribution, chains, and the radioactivity of fission products, including calculation of amounts of reactor products. The text, together with the many excellent illustrations and tables, outline the rationale behind the approach to fission product disposal. H. A. C. McKay contributes a short section on $\alpha$-emitters. In Part 2 we encounter the various effects of radiation on materials and organisms. There are chapters on physical and chemical

effects on materials and living cells, the movement of radioactive species in food chains, and the various occupational and public health implications, supplemented by Part 3—legal aspects. The many radioactive effluent treatments and disposal methods are surveyed very thoroughly in Part 4. There are methods for low-activity treatment, including chemical methods, ion exchange, evaporation, sludge treatment, biological decontamination, sea, river and ground disposal, while the procedures adopted at Chalk River, ORNL, Hanford and Harwell are described in detail. Further sections deal with high-activity processing of wastes, conversion into solid products, chimney stack effluents, and separation of individual fission products. The possibilities of utilizing fission products are not overlooked and Part 5 deals with reactor radiation, gross and isolated fission products, cobalt-60 sources, and packaged irradiation sources. Part 6 deals with the application of such sources for agriculture, food preservation, and industrial chemical processing. There have been many books dealing with fission products, but it is doubtful whether any have been so authoritative, so free from guesswork, so ably edited, and so well-conceived as this one. The editor, Dr. Glueckauf, ends his introduction with the words: "It is hoped that this book succeeds in illuminating the background from which such future developments can emerge." Personally, I feel that the word "illumination" is too relative, and too modest. "Brilliance" might have been better applied to this particular work. F.R.P.△△△

# *Semi-homogeneous critical assembly*

*by Noriyuki Sakikawa*

A SEMI-HOMOGENEOUS experimental breeder reactor with a core of powdered enriched uranium and graphite is under development by the Japan Atomic Energy Research Institute. Originally the reactor was designed to separate fission products easily by making the graphite of the neutron moderator absorb them. Now, however, it is being developed as a breeder to produce uranium-233 and has thorium-232 mixed with the fuel and graphite.

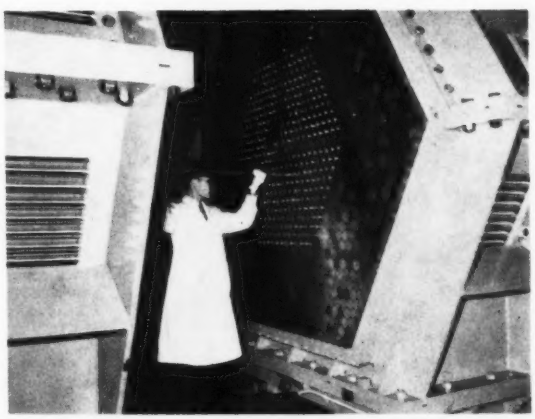
In the first development stage, a critical assembly was constructed and put into operation in January of this year. It was designed and developed by Dr K. Inoue, Dr. K. Sumita and other scientists at the Institute.

The assembly consists of two half-sections which can be moved together to create a critical mass for an experiment. The structure consists of graphite reflector rods and the core matrix of fuel elements. These elements are piled on top of each other to form a hexagonal lattice. The shape of the core and mixing ratio of the components (enriched uranium, thorium and graphite) can be adjusted to study the behaviour of the assembly. Eight safety rods have been provided for control purposes.

## *Start-up*

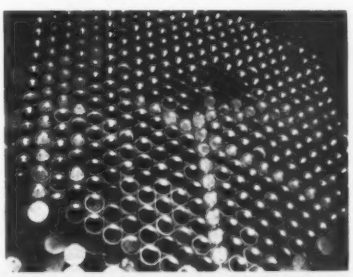
To start the assembly an antimony-beryllium source is placed in a graphite reflector near the centre of the core, this is later removed when critical mass has been attained.

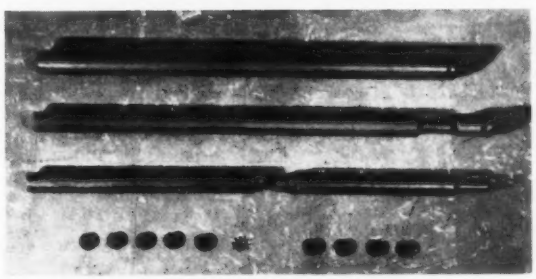
The safety factor is very high because of the large negative temperature coefficient and high heat-resistivity of the core materials.△△



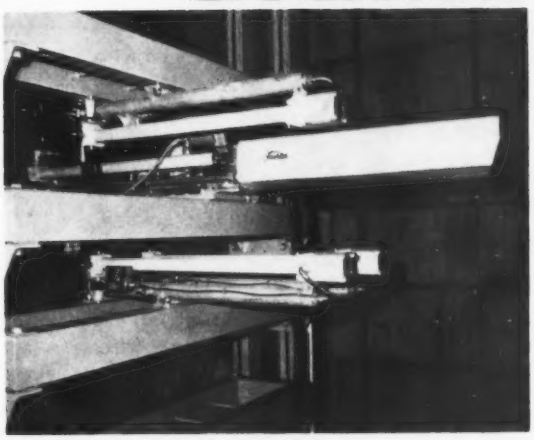
(*Left*) **Semi-homogeneous critical assembly**

(*Right*) **Structure of the reactor core. Each graphite clad contains discs of fuel mixture of uranium, thorium and graphite. Critical mass can be attained with 329 fuel rods**





**Fuel element, graphite clad and fuel discs**



**Control system**

# NUCLEAR NOTES

## Safety system

A EUROPEAN system for supervision of environmental radioactivity and emergency warning in cases of abnormal increases has been set up under a decision of the OEEC council. Under the system, which was worked out by the European Nuclear Energy Agency, any important increase in radioactivity observed in any member country will be communicated to the appropriate authorities in other member countries and to ENEA, so that any necessary national measures for health protection can be taken without delay.

## Soviet aid

A SUPPLEMENTARY protocol to the Polish-Soviet agreement regarding aid and mutual co-operation in the utilization of nuclear energy has been signed. The protocol provides for the further expansion of co-operation in various branches of atomic science.

## Refuelling machine

AMF Atomics have been awarded an AEC contract for a Canadian power reactor refuelling machine. Estimated cost of the contract is about $1,600,000. The refuelling machine will be used in connection with pressure tube type, heavy water moderated, natural uranium-fuelled power reactors. The project's objective will be to develop a machine which will permit the loading and unloading of reactor fuel elements in pressure tubes while the reactor is operating at full power.

## Plasma physics

AN international conference on plasma physics and controlled nuclear fusion research will be held by the International Atomic Energy Agency at Salzburg, Austria, from September 4th to 9th.

## U.S.-Euratom project

EURATOM and the U.S. Atomic Energy Commission have signed contracts with the Societá Elettronucleare Nazionale for the first project of the U.S.-Euratom joint power programme.

## Element handling

REMOTE handling equipment for the decanning and decontamination caves at Windscale has been ordered by the Atomic Energy Authority from GEC, Ltd. The equipment is to be used for handling the irradiated fuel elements of the Authority's nuclear stations such as Calder Hall and the first of the CEGB nuclear stations. Commissioning of the equipment is scheduled for the spring of next year.

## Digital analysis

AN order has been received by Compagnie Européenne d'Automatisme Electronique from the French Atomic Energy Organization for a system for automatic digital analysis of measurements for the test model of " Rapsodie," a fast reactor.

## High-flux reactor

A HIGH-FLUX research reactor is nearing design completion for the National Bureau of Standards' new site at Gaithersburg, Maryland. The reactor will provide the high-intensity and high-energy fluxes required for the Bureau to establish precision measurement techniques and standards in the reactor field and in areas of basic scientific research. The thermal beams provided will be utilized through the new analytical technique of neutron diffraction to study basic structural properties of matter. Other investigations will be concerned with, for example, radiation effects, chemical analysis, diffusion and fission. The Bureau will share the use of the reactor with various Government agencies in the Washington area,

## Rover review

CHAIRMAN of the American joint committee on Atomic Energy Research and Development Subcommittee, Mr. M. Price, is considering establishment of a panel of consultants to review the plans for the Rover nuclear rocket project.

## Greek AMF reactor

THE 16th AMF research reactor was recently opened in Aghia, near Athens. Called the Democritus Nuclear Research Centre, it is of 1,000 kW capacity.

## Finned tube process

OVER 600,000 ft of welded finned tube made by a new process is to be supplied by the Extended Surface Tube Co., Ltd., Broad Street Chambers, Birmingham, for use in the boiler of Dungeness nuclear power station. In this process, using powerful welding current generators, cold rolled strip is welded to the tube as it is helically wound on to form the fin. As a result of strict control, a weld bead is produced which is small and consistent in quality and allows more fins per inch. Up to seven fins per inch are accepted as standard.

## Tannoy warning

TO give early warning of reactor faults, the Windscale works of the Atomic Energy Authority have installed four Tannoy systems. These communication and warning systems have a total output of nearly 1 kW and are complete with transistorized coded warning oscillator.

## More uranium

THE chairman of the Comisión Nacional de Energia Atómica, of Argentina, has announced the discovery of another uranium deposit in the Province of Chubut, 200 km from Rawson.

## Dutch reactor design

A COMBINE of six Dutch industrial enterprises, NV Neratom, has received an order from Euratom for making a design of a small reactor of 1 kW for investigating the behaviour of fissile material elements. The design will be carried out in conjunction with the Ingenieursbureau Comprimo, of Amsterdam; the Advies- en Constructiebureau Tebodin and the Reactor Centre of the Netherlands of the Hague.

## Calder graphite check

TO find out what effects 4½ years' irradiation has had on the graphite moderator in the Calder Hall reactors, Authority engineers used a Pye miniature TV camera 3 in. in diameter to operate inside the core. Another small tool was developed, with the Langham Engineering Co., to cut pieces of graphite out of the reactor for inspection. The result? Graphite in the reactors has grown slightly in size as a result of irradiation. This is Wigner growth and, due to the way the graphite is stacked, takes place mainly horizontally.

## Fuel element contract

A CONTRACT has been signed by Babcock & Wilcox Co. and Aerojet General Nucleonics for the former to supply 20 fuel elements for the University of Basle reactor, Switzerland.

## Slow neutron sifting

THE Atomics Division of American Machine & Foundry Co. has developed a new method to sift the slow neutrons out of the broad spectrum of radiation given off by a reactor, which could be valuable in medical therapy. It is called the Syftor. This new concept consists of a fast-pulsed reactor, an external moderator and a mechanical arrangement that pulses and screens the core in synchronism. The first Syftor design is expected to produce an

# NUCLEAR NOTES

integrated flux of $10^{13}$ nvt at the dose point in 100 min, while non-thermal neutrons and gammas are held to 100 r. Modifications could produce the same flux in two minutes.

## Radiospectroscopy

THE Institute of Physics and The Physical Society and the British Radio Spectroscopy Group are holding a two-day conference on radiospectroscopy of solids in the Department of Physics of the University College of North Wales, Bangor, on September 21st and 22nd.

## OEEC courses

THE European Nuclear Energy Agency of the OEEC has published a new edition of its "Catalogue of Courses on Nuclear Energy in OEEC Countries." This catalogue is designed to help science and engineering students who wish to acquire a better knowledge of nuclear subjects to find out what training facilities are available. University authorities and others wishing to compare the programmes of technical establishments in the different countries will also find much relevant information. The new catalogue covers the 1961-62 academic year and gives details of training courses in subjects relating to nuclear energy in some 180 Western European universities, technical high schools and research centres.

## Radiation safety

THE City and Guilds of London Institute have introduced a new examination intended to provide a basic qualification for full-time non-professional supporting staff employed on health and safety duties in those industries using radiation and radioactive materials. The decision to offer this examination was taken after considering a request from the United Kingdom Atomic Energy Authority, who were implementing the recommendation on the training of Category C personnel made in the Report of Sir Douglas Veale's Committee on Training in Health and Safety.

## Book donations

THE U.S.A. is donating a large number of books on atomic energy for peaceful purposes to Gadjah Mada University, in Jogjakarta, and to the Institute of Technology in Bandung, Indonesia. The former will use them in connection with its isotope laboratory financed by the U.S.A. and now being set up; those for the Institute will be of use in mastering the nuclear reactor to be installed in Bandung.

## Bodega Bay

NEW developments in boiling water reactor technology made by U.S. General Electric will be incorporated in a 325,000 kW nuclear power plant to be built at Bodega Bay, near San Francisco, California, by Pacific Gas and Electric Co. Construction should start in 12 months. Pressure suppression, a method of reactor containment, will be a special feature of the plant and design refinements will include improved calculation techniques and criteria, improved instrumentation systems and high-performance internal steam separators.

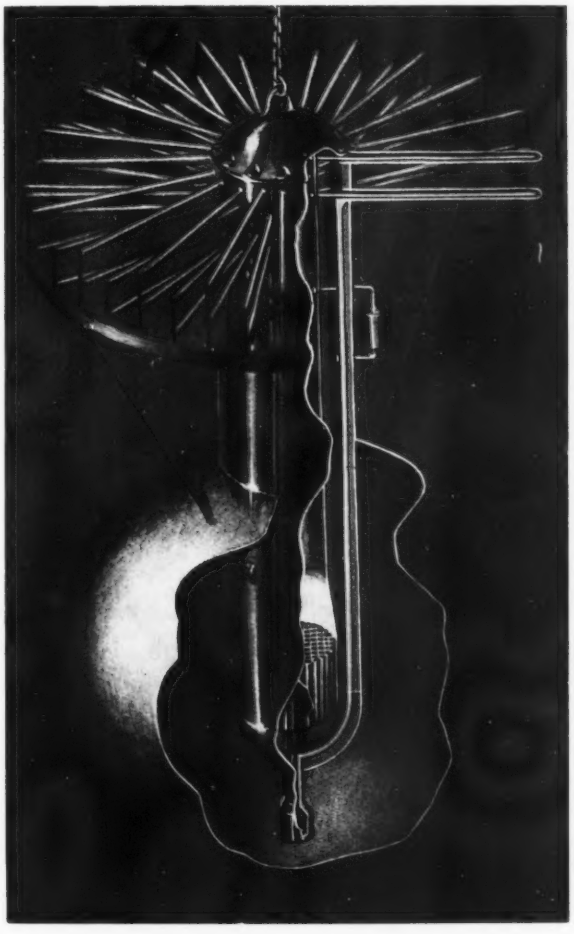
## UKAEA annual report

NOW available from the U.K. Atomic Energy Authority is an illustrated summary of their seventh annual report from April 1st, 1960 to March 31st, 1961. Featured in this report are improvements made at Calder Hall, the Authority's power programme, the future of reactors, fuel elements and many other items of interest. Price is 2*s.* 6*d.*

## Atomic Energy, No. 13

ISSUE No. 13 of *Atomic Energy*, published by the International Atomic Energy Agency, in Austria, is now available. It contains a list of conferences, meetings and training courses which is designed to promote exchange of information and help scientists to make personal contacts. The subjects are related mainly to the basic scientific and technical aspects of nuclear energy and its peaceful applications. The first part covers meetings which will be held during

# Self-regulating power plant



A PORTABLE self-regulating atomic power plant to generate electricity beneath the surface of the sea or in remote land areas of the world without requiring any operating personnel is being developed by General Dynamics Corporation. The self-operating plant will be equipped with homogeneous fuel and moderator elements of uranium-zirconium hydride similar to those which ensure the self-regulated safety of TRIGA research reactors presently in use on five continents.

# NUCLEAR NOTES

the next 12 months. The programmes of some of these meetings deals exclusively with subjects relating to nuclear energy. The second part deals with meetings during the second 12 months. Specialized training courses at different levels are listed in the third part under three headings.

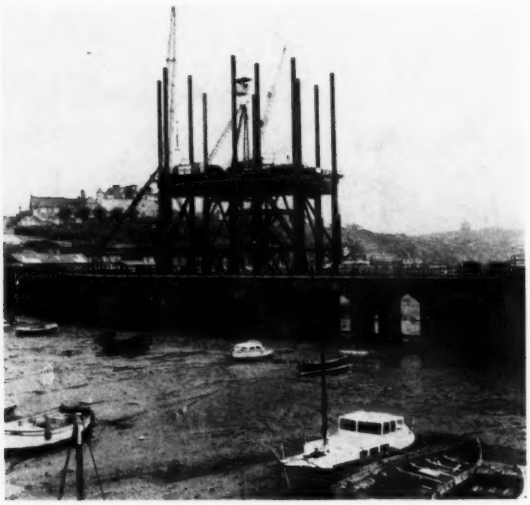
## Bulletin, Vol. 3

VOLUME three of the International Atomic Energy Agency *Bulletin* has been published. Its contents include disposal of radioactive wastes, progress in nuclear electronics, methods of estimating nuclear power cost, tritium in the physical and biological sciences and radioisotopes in Burmese agricultural research. Other articles deal with atomic prospects in four African states, medical research with radioisotopes in Greece, the OEEC European Nuclear Energy Agency and conferences and training courses relating to atomic energy.

## Radiation uses

PROCEEDINGS of a conference on the technological use of radiation, held in Sydney, Australia, in May, 1960, forms the contents of a recent booklet published by The Australian Atomic Energy Commission, price 30*s*. It is entitled " The Technological Use of Radiation, 1960."

## *Dungeness cooling-water structure*



FLOATING a 1,100-ton metal water intake from Folkestone to Dungeness nuclear power station was recently achieved by its manufacturers, Sir Robert McAlpine & Sons. At Dungeness it was lowered to the sea bed 1,000 ft from the shore. The cooling water intake now stands astride the cooling water tunnel from the station in the Channel. The orthodox cofferdam method around the tunnel's seaward end was considered risky so a new method was employed. The eventual plan was to tunnel out from the shore to the terminal point of the tunnel, plug the end with concrete, break through the roof of the tunnel with two vertical " push-up " tubes and then break out again through the overburden into the bed of the Channel. When the tubes are through they will be stopped up with large plugs enabling the tunnel workers to break through the tunnel roof into the " push-up " tubes and remove the encased overburden. The octagonal working platform is carried on a tubular structure 90 ft across and 75 ft from base to deck level. It has three horizontal frames of 1 ft 6 in. diameter tubes with braces and diagonals of the same diameter. Twelve 3 ft diameter tubes will form the legs. To provide sufficient buoyancy, four main flotation tanks were attached to the sides of the octagon in guide frames which allowed the tanks to rise and fall with the tide until required. Then they were pinned down at their lowest point ready for launching. The four tanks were completely under control by hydraulic jacks which could raise or lower the structure at will. Further buoyancy was obtained by the addition of smaller, lighter fixed sectional tanks in the main corners of the octagon. This extra buoyancy widened the choice of tides on which the structures could be floated. The towing operation involved three deep-sea tugs with two attendant vessels. On arrival at Dungeness the 12 piles were screwed home to a depth of about 50 ft. The hollow screw piles were excavated by means of an air lift pump, then filled with reinforced concrete. Flotation tanks were removed and the structure was ready to carry out its function of operating the " bath plugs " and help with the tunnel break-through into the Channel. This intake structure will remain an eventual part of the nuclear power station, guarding the seaward end of the intake tunnel and providing the working platform from which the tunnel will be closed when necessary for maintenance purposes. The entrance to the harbour is 106 ft wide at mud level while the structure is 98 ft at its widest point.

# Monographs received

**The Measurement of Pressure Gradient in High Current Discharges,** by M. G. Rusbridge. Published by CTR Division, AERE, Harwell. Reference AERE-R3578. Available from H.M. Stationery Office. Price 2*s*. 6*d*.

**A Stabilized Current Supply of Extended Range (1-6A) for Use with Thermal Emission Ion Sources,** by R. Hallett. Published by Chemistry Division, AERE, Harwell. Reference AERE-R3385. Available from H.M. Stationery Office. Price 1*s*. 9*d*.

**A Mercury Computer Programme for the Analytical Refinement of Crystal Unit Cell Parameters by the Method of Least Squares,** by E. Wait. Published by Chemistry Division, AERE, Harwell. Reference AERE-R3598. Available from H.M. Stationery Office. Price 2*s*. 6*d*.

**The Identification of Beta-emitting Isotopes by Liquid Scintillation Counting,** by W. P. Hutchinson. Published by the Medical Division, AERE, Harwell. Reference AERE-R3605. Available from H.M. Stationery Office. Price 2*s*. 6*d*.

**The Derivation of a Generalised Chart for Spiral-groove Thrust Plate Performance,** by P. Fortescue. Published by AERE, Harwell. Reference AERE-M804. Available from H.M. Stationery Office. Price 1*s*. 9*d*.

**Fission Product Ruthenium in Effluent Treatments,** by E. R. Gardner and P. G. M. Brown. Published by Chemistry Division, AERE, Harwell. Reference AERE-R3551. Available from H.M. Stationery Office. Price 1*s*. 9*d*.

**A Remote Reading Gamma Dose-rate Meter and a Training Instrument for Civil Defence,** by K. E. G. Perry and J. E. Maddock. Published by Electronics Division, AERE, Harwell. Reference AERE-R3532. Available from H.M. Stationery Office. Price 4*s*. 6*d*.

**Radioisotope Data,** by R. A. Allen, D. B. Smith and J. E. Hiscott. Published by Isotope Research Division, Wantage Research Laboratory. Reference AERE-R 2938 2nd edition. Available from H.M. Stationery Office. Price 8*s*.

**Analytical Method for the Absorptiometric Determination of Trace Thorium in Uranium Solutions,** by T. J. Hayes. Published by Production Group, Risley. Reference PG Report 2(S). Price 1*s*. 6*d*.

**Analytical Methods for The Determination of Iodine-131 in Vegetation, Milk, Thyroid Glands and Natural Waters,** by Technical Manager (Chemistry), Windscale Works. Available from H.M. Stationery Office. Price 2*s.* 6*d.*

**Analytical Method for The Determination of Niobium-95 in Reactor Fuel Processing and Effluent Treatment Plant Solutions,** by Technical Manager (Chemistry), Windscale Works. Available from H.M. Stationery Office. Price 1*s.* 9*d.*

**The Application of Gas-Liquid Chromatography to the Analysis of Corrosive Gases,** by G. Iveson, Technical Department, Capenhurst. Available from H.M. Stationery Office. Price 3*s.*

**Extraction of Plutonium by Means of Tributyl Phosphate,** by E. I. Moiseenko and A. M. Rozen. Obtainable from the UKAEA, Risley, Warrington, Lancs.

**Bibliography of Beryllium and Beryllia,** by U. R. M. Chadwich, Library and Information Department, Reactor Technology Branch, Risley. Available from H.M. Stationery Office. Price 3*s.*

**Tentative Designs for Two Geometrically Eversafe Mixer Settlers for High Volumetric Throughputs,** by C. Hanson, formerly R. & D. Branch, Risley and M. J. S. Smith, Central Technical Services, Reactor Technology Branch, Risley. Available from H.M. Stationery Office. Price 3*s.*

**The Distribution of Flux and Temperature in Thermal Fuel Rods,** by I. S. McGill, Dounreay Experimental Reactor Establishment. Available from H.M. Stationery Office. Price 3*s.* 6*d.*

**Reactors at the Atomic Energy Research Establishment, Harwell,** by C. S. Sabel, G. A. Bell and Miss G. M. Wildish, Library Information Office, AERE, Harwell. Available from H.M. Stationery Office. Price 5*s.*

**Hydromagnetic Stability Theory, a Brief Survey,** by R. J. Tayler, Culham Laboratory, Culham. Available from H.M. Stationery Office. Price 2*s.* 6*d.*

**Biology and Man,** by T. E. Graham. Published by Radiological Protection Division, Harwell. Reference AHSB(RP)L5. Available from H.M. Stationery Office. Price 7*s.*

**Analytical Method for the Polarographic Determination of Zinc in Magnox Alloy,** presented by Technical Manager (Chemistry), Operations Branch, Windscale. Published by Production Group, Risley. Reference PG Report 181(W). Price 1*s.* 6*d.*

**Recommended Practice in the Safe Handling of Plutonium in Laboratories and Plants,** by G. J. Appleton and H. J. Dunster. Published by Authority Health & Safety Branch, UKAEA, Harwell. Reference AHSB(RP)R6. Available from H.M. Stationery Office. Price 7*s.*

**A Field Emission Microscope for Adsorption Studies,** by R. J. Hill. Published by Metallurgy Division, UKAEA, Harwell. Reference AERE-R3652. Available from H.M. Stationery Office. Price 3*s.* 6*d.*

**Thermal Strains in a Heat Producing Elastic-Plastic Cylinder,** by J. P. Ellington. Published by Development & Engineering Group, UKAEA, Risley. Available from H.M. Stationery Office. Price 2*s.* 6*d.*

**The Analytical Chemistry of Beryllium.** Proceedings of a Symposium, edited by J. Metcalfe and J. A. Ryan. Published by Production Group, UKAEA, Risley. Reference PG Report 171(S). Price 12*s.* 6*d.*

**The Paper Chromatographic Separation and Assay of $^{90}Sr$ and $^{90}Y$,** by P. M. Naylor. Published by Development & Engineering Group, UKAEA, Risley. Reference DEG Report 317(W). Available from H.M. Stationery Office. Price 1*s.* 6*d.*

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**Suggested Design Methods for the Application of Spray Evaporations to a Steam Cooled Heavy Water Moderated Reactor,** by J. G. Collier. Published by Chemical Engineering Division, UKAEA, Harwell. Reference AERE-M707 (unclassified version of IG Memo 572 (RN/R). Available from H.M. Stationery Office. Price 3*s.*

**Flux Measurements in a Dummy In-pile Irradiation Facility in Lido,** by H. R. McK. Hyder, C. J. Kenward, A. Green and E. D. Jones. Published by Chemistry Division, UKAEA, Harwell. Reference AERE-M845. Available from H.M. Stationery Office. Price 1*s.* 9*d.*

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**A Thermal Neutron Scintillation Counter for Use in Neutron Scattering Experiments,** by D. H. C. Harris. Published by Nuclear Physics Division, AERE, Harwell. Reference AERE-R3688. Available from H.M. Stationery Office. Price 3*s.*

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**The Determination of Fluoride in Aqueous Effluent (Absorptiometric-Aluminium/Haematoxylin),** presented by Chief Chemist, Technical Department, Capenhurst. Published by Production Group, UKAEA, Risley. Reference PG Report 189(CA). Price 1*s.* 6*d.*

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**The Determination of Uranium-234 in Enriched Uranium Hexafluoride, Tetrafluoride and Oxide by an Alpha-Counting Technique,** presented by Chief Chemist, Technical Department, Capenhurst. Published by UKAEA. Production Group, Risley. Reference PG Report 194(CA).

**Cylindrically Symmetrical Hydromagnetic Disturbances in a Plasma,** by J. H. Adlam, K. Hain and I. C. Pyle. Published by CTR Division & Theoretical Physics Division, AERE, Harwell. Reference AERE-R3643. Available from H.M. Stationery Office. Price 4*s.* 6*d.*

**Investigation of $BF_3$ Proportional Counters,** by H. F. Brinckmann and D. Gerber. Published by Research Group, AERE, Harwell. Reference AERE-Trans. 859.

**Strontium 90 in Milk and Agricultural Materials in the U.K., 1959-1960.** Published by Radiobiological Laboratory, Agricultural Research Council. Available from H.M. Stationery Office. Price 5*s.*

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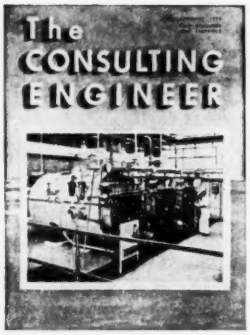


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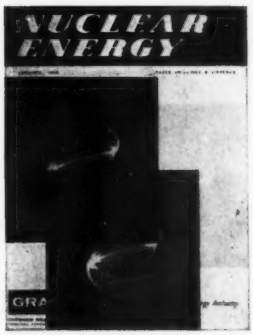


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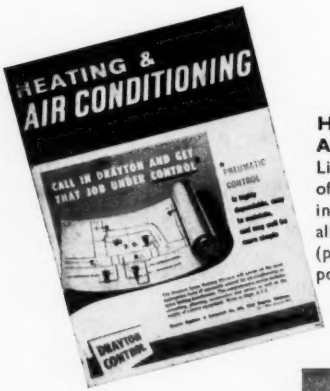


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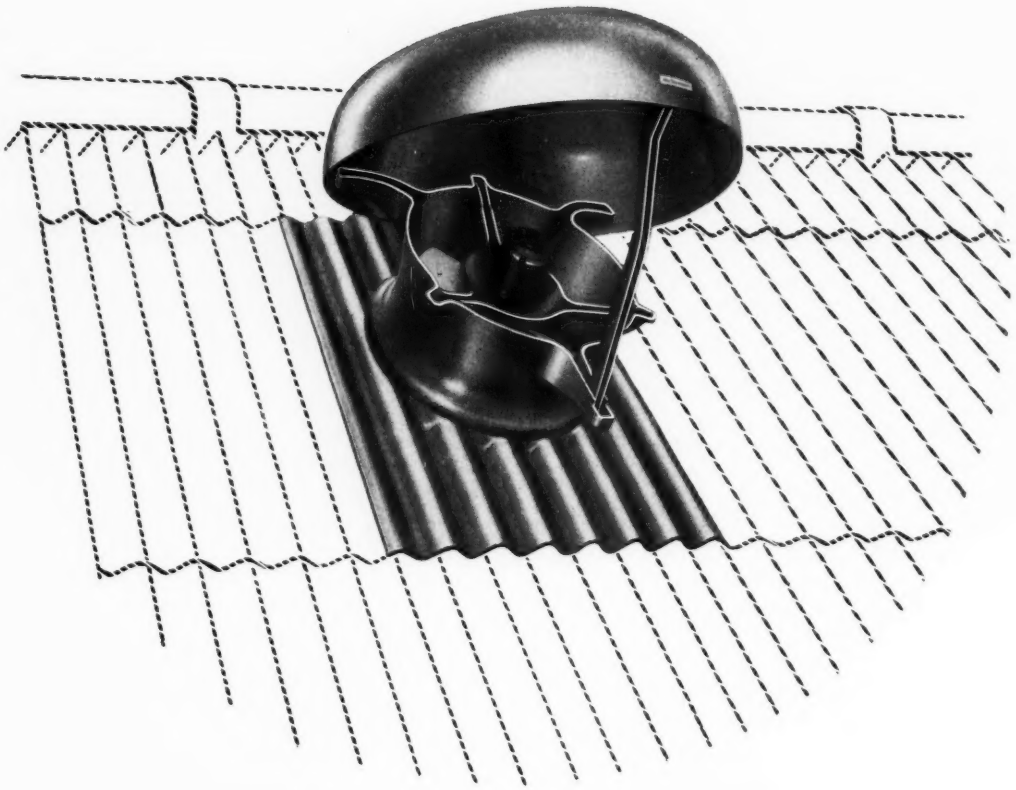

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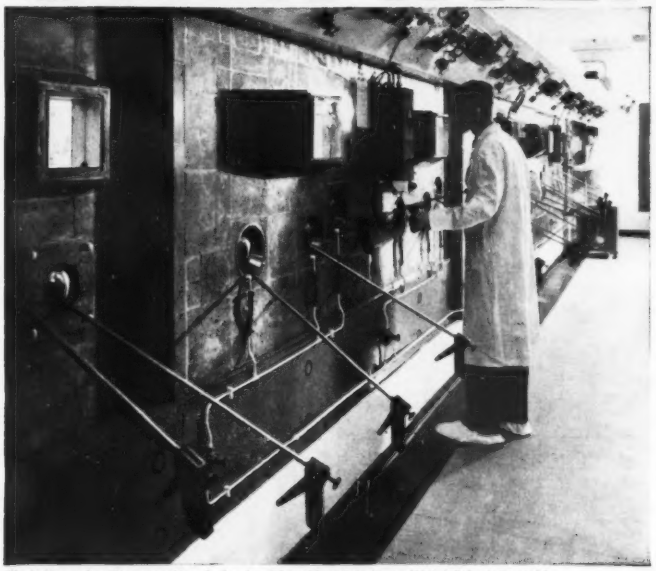

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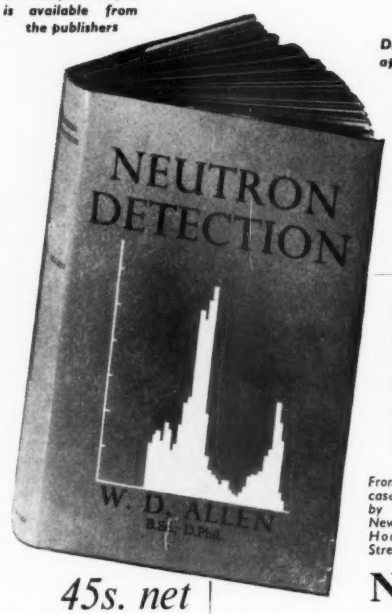


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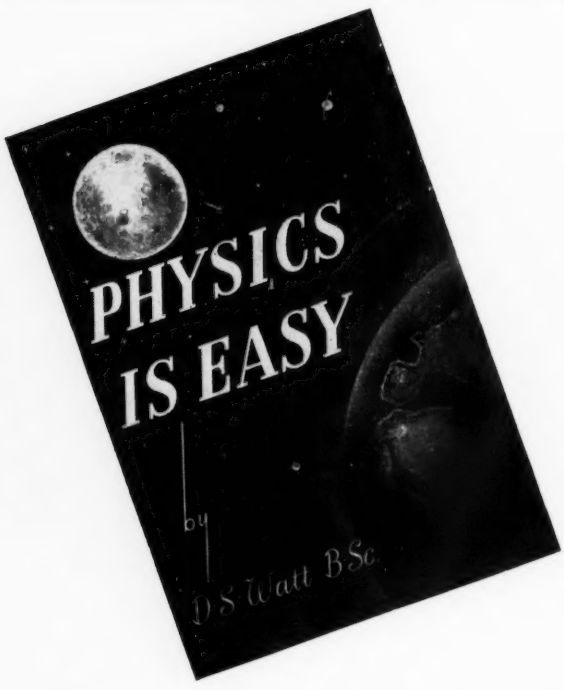


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